

# FALLOUT FROM NUCLEAR WEAPONS TESTS

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## HEARINGS

BEFORE THE

SPECIAL SUBCOMMITTEE ON RADIATION

OF THE

JOINT COMMITTEE ON ATOMIC ENERGY

CONGRESS OF THE UNITED STATES

EIGHTY-SIXTH CONGRESS

FIRST SESSION

ON

FALLOUT FROM NUCLEAR WEAPONS TESTS

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## NOTE

This is volume 3 of the public hearings held May 5-8, 1959, on "Fallout From Nuclear Weapons Tests." This volume is an appendix to the hearings containing additional materials pertinent to the discussions. These materials cover Supplemental Statements on General Aspects of Fallout Problem; the "Hot Spot" Problem and Strontium 90 in Foods; AEC Quarterly Reports; Comments on General Advisory Committee Report; Maximum Permissible Levels; Biological Effects; Carbon 14; Report of the United Nations Scientific Committee on the Effects of Atomic Radiation--1958; Nuclear Detonations and Meteorological Aspects; Classification and De-classification; Fallout Research and Organization; and a Bibliography. Volume 1 covers General Review of Developments Since the 1957 Hearings; Summary of New Data on Atmospheric Fallout; and Global Fallout. Volume 2, starting with a Summary of New Data on Uptake in Milk, Food, and Human Bone, covers Fallout Mechanisms, Uptake; Developments in Radiation Biology; Discussion of Permissible Exposure Levels; Status and Implications of Testing; Discussion of Surveillance; and Summary of Problems and Needs, Including Level of Support. It is planned at a later date to publish a detailed index of the hearings. The index would appear as volume 4.

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## APPENDICES

### APPENDIX A

#### STATEMENTS FOR THE RECORD ON GENERAL ASPECTS OF FALLOUT

##### A REVIEW OF INFORMATION ON THE GAMMA ENERGY RADIATION RATE FROM FISSION PRODUCTS, AND ITS SIGNIFICANCE FOR STUDIES OF RADIOACTIVE FALLOUT

(By Harold A. Knapp)

Office of Operations Analysis and Forecasting, U.S. Atomic Energy Commission,  
April 24, 1959

#### SUMMARY

Recent independent studies by the Naval Radiological Defense Laboratory and by scientists and engineers concerned with the shielding of nuclear reactors indicate that the gamma energy radiation rate from fission products of thermal neutron fission of  $U^{235}$  for times between several minutes and 100 years differs significantly from the value predicted by the  $t^{-1.2}$  decay law and other information given in the official Government publication "The Effects of Nuclear Weapons." The difference occurs both in the absolute level of the energy release rate from a given quantity of fission products at some standard time following fission (usually taken as 1 hour), and in the relative variation of this rate with time.

Based on "The Effects of Nuclear Weapons," the gamma radiation rate is computed to be  $0.58t^{-1.2}$  Mev/sec/10<sup>4</sup> fissions (t in hours). At 1 hour this rate is lower than that computed by the NRDL by a factor of 2.3; at 2 years it is greater by a factor of 7. The differences at other times are shown in table 1. A release rate of  $0.87t^{-1.2}$  Mev/sec/10<sup>4</sup> fissions approximates the NRDL computations to within 25 percent for times between 6 hours and 3 months following fission, but such a rate is uniformly 50 percent greater than that predicted by the rules given in "The Effects of Nuclear Weapons." Changes in the gamma energy release rate associated with a given quantity of fission products may be reflected in estimates of the fraction of the fission products created in a surface burst nuclear explosion which fall to earth as part of the local fallout, which in turn affects estimates of the fraction contained in the global fallout. This is because the fraction of the fission products contained in the local fallout has often been estimated by computing the areas associated with each dose rate level measured in roentgens/hour at 1 hour and deducting from this information the area distributions and total quantities of fission products contained in the local fallout on the basis of the data given in "The Effects of Nuclear Weapons." Since the open field gamma dose rate in roentgens/hour from the radioactivity in fallout is very nearly proportional to the gamma energy release rate per unit area, a change in the gamma energy radiation rate associated with a given quantity of fission products will be reflected in a change in the quantity of fission products per unit area on the ground associated with a given measured dose rate level in roentgens/hour. The differences between the NRDL and "Effects of Nuclear Weapons" estimates of the roentgen dose rate associated with a fission product contamination level of 1 kiloton per square mile are shown in table 2.

Another situation in which the differences between the NRDL computations and the information given in "The Effects of Nuclear Weapons" are of particular interest arises in comparisons of the relative importance of fission products and induced activities for weapons of reduced fission yield.

A review of available information on the energy release rate of fission products indicates that the NRDL results provide a more accurate representation of the

gamma energy release rate of the fission products from the thermal fission of  $^{235}\text{U}$  than does the information given in "The Effects of Nuclear Weapons," although this has not been confirmed by direct measurements for all time periods of interest. However, even if the energy release rates computed on the basis of the latest nuclear data are accurate for the thermal fission of  $^{235}\text{U}$ , there are three ways in which differences might arise between these results and the gamma energy release rate of fission products in weapons debris:

1. Fissions in weapons are caused by neutrons with much higher energies than thermal neutrons, and the relative yields of the various fission products change as the energy of the neutrons causing fission changes.

2.  $\text{Pu}^{239}$  and  $\text{U}^{238}$  are fissioned in many weapons, as well as  $^{235}\text{U}$ . In some high yield weapons a major fraction of the fissions is from  $\text{U}^{238}$ . There are known differences in the fission yields of the different fissionable materials.

3. There may be fractionation of isotopes in weapons debris which would cause the gamma energy release rate for the fission products found in the local fallout to differ at certain times following detonation from the release rate of the same number of fission products in the global fallout, and in both cases to differ from the release rate which would obtain if there were no fractionation—that is, if all fission products attach themselves to fallout particles in the same proportions as they were created.

Another complexity is introduced into measurements of the gamma energy radiation from actual weapons debris by the many activities induced in weapons materials and elements in the earths crust by the neutrons released in the detonation. At the present time it is often not possible to give a satisfactory explanation as to the measured shape of the gamma dose rate curve or to give a very firm estimate of the distribution of the radioactivity generated between the local and global fallout.

#### DISCUSSION

It is very nearly true that the open field, external dose rate in roentgens/hour caused by the fission products in radioactive fallout is proportional to the emission rate of the fission products. At present, most estimates of external gamma dose rates from the fission product fallout following an atomic or thermonuclear explosion are based on rules and information provided in "The Effects of Nuclear Weapons."<sup>1</sup> Recent studies, however, indicate that the standard assumptions concerning gamma radiation rates from fission products may contain significant errors, particularly at times from 6 months to 3 years following detonation, but also in the first hours and days after the explosion.

The first object of this report is to summarize available information concerning the gamma photon energy radiation rate from fission products, and to indicate the specific assumptions which now seem most suited for fallout evaluations.

Determination of the gamma energy radiation rate from fission products may be broken down to two separate problems:

1. The relative variation in the energy release rate with time.
2. The absolute level of the energy release rate at some (standard) time from a fixed quantity of fission products.

The recent studies indicate significant differences with the official estimates on both counts.

The results given here will be expressed as  $\text{Mev/sec}/10^4$  fissions. They can be translated to  $\text{Mev/sec/kt}$  fission or to  $\text{kw/megawatt day}$  of fission by the relations

$$1 \text{ Mev/sec}/10^4 \text{ fissions} = 1.34 \times 10^{13} \text{ Mev/sec/kt fission} \\ = 44.8 \text{ kw/megawatt day fission}$$

According to "The Effects of Nuclear Weapons":

"9.110 The mixture of radioisotopes constituting the fission products is so complex that a mathematical representation of the rate of decay in terms of individual half lives is impractical. However, it has been found experimentally that for the period from several minutes to 2 or 3 years [italic added] after detonation the overall rate of radioactive disintegrations (or rate of emission of radiations) by the fission products can be represented, to a fair degree of accuracy, by the relatively simple expression

$$(9.110.1) \text{ Rate of Disintegration} = A_1 t^{-1.2}$$

<sup>1</sup> Prepared by the Department of Defense, published by the AEC, June 1, 1957.

where  $t$  is the time after formation of the fission products; i.e., the time after the explosion, and  $A_1$  is a constant factor, defined as the rate of disintegration at unit time, that is dependent upon the quantity of fission products. This equation can also be used, with appropriate values for  $A_1$  to give the rate of emission either of gamma rays or of beta particles. A beta particle is liberated in each act of disintegrations, but gamma ray photons are produced in about one-half only of the fission product disintegrations, the fraction varying with time after the explosion.

"9.111 In considering the radiation dose (or dose rate) due to fission products; e.g., in fallout, the gamma rays, because of their long range and penetrating power, are of greater significance than the beta particles, provided the radioactive material is not actually on the skin or within the body. Consequently the beta radiation can be neglected in estimating the variation with time of the dose rate from the residual nuclear radiation. If the fraction of fission product disintegration accompanied by gamma ray emission and the energy of the gamma ray photon remained essentially constant with time, the dose rate; e.f., roentgens/hour, would be directly related to the rate of emission of gamma rays. As mentioned in paragraph 9.34, this is not the case. The gamma rays in the early stages of fission product decay have, on the average, higher energies than in the later stages. However, for the periods of practical interest, commencing a few hours after the explosion, the mean energy of the gamma ray photons may be taken as essentially constant, at about 0.7 Mev.

"9.112 Although the fraction of gamma emitters varies with time, a fair approximation based on equation (9.110.1) is that, at any time  $t$  after the explosion

$$(9.112.1) \text{ Gamma radiation dose rate} = R_1 t^{-1.2}$$

where  $R_1$  is a constant.

"9.119 \* \* \* using equation (9.110.1) as the basis, the total gamma activities of all the fission products from a 1-megaton explosion have been calculated for various times after the detonation. The results are given in table 9.119.

TABLE 9.119.—Total gamma radiation activity of fission products from a 1-megaton explosion

| Time after explosion: | Activity<br>(megacuries) |
|-----------------------|--------------------------|
| 1 hour.....           | 300,000.0                |
| 1 day.....            | 6,000.0                  |
| 1 week.....           | 640.0                    |
| 1 month.....          | 110.0                    |
| 1 year.....           | 5.5                      |

#### RADIATION DOSE RATES OVER CONTAMINATED SURFACES

"9.120 If an area is uniformly contaminated with any radioactivity of known activity (in curies), it is possible to calculate the gamma-radiation dose rate at various heights above the surface, provided the average energy of the gamma ray photons is known. The results of such calculations, assuming a contamination density of 1 (gamma) megacuries per square mile, for gamma rays having energies of 0.7 Mev, 1.5 Mev, and 3.0 Mev respectively, are represented in figure 9.120. The curve for 0.7 Mev is approximately applicable to a surface contaminated with fission products."

NOTE.—The 0.7 curve shows a dose rate of 4.2 r/hr at 3 feet above the ground from a contamination level of 1 megacurie per square mile. The dose rate at this height for activities with other gamma photon energies vary approximately linearly with photon energies, so that 1 Mev photons would produce a dose rate of about 6 r/hr/megacuries/ $\text{mi}^2$ .

This information—namely the  $t^{-1.2}$  decay law, the 300 megacuries/kt at 1 hour following explosion, and the average photon energy per disintegration of .7 Mev—together with the conversion factor  $1 \text{ kt} = 1.34 \times 10^{13}$  fissions, enables one to compute a gamma energy release rate in  $\text{Mev/sec}/10^4$  fissions for ready comparison with the more recent data. The results are shown in table 1. The analytical representation is given by

$$\text{Mev/sec}/10^4 \text{ fission} = .58 t^{-1.2} \quad (t \text{ measured in hours})$$

Recent studies by the Naval Radiological Defense Laboratory<sup>2,3,4</sup> have mathematically synthesized the known facts concerning the formation and gamma decay of individual fission products to give a tabular representation of the energy emission rate as a function of time. These results are also shown in table 1. It is seen from table 1 that the NRDL results vary appreciably both above and below the energy release rate based on the standard assumptions. For the first day, the NRDL predicted gamma energy release rate is roughly twice that given by "The Effects of Nuclear Weapons"; from 1 day to 1 month it is generally higher by a factor of about 50 percent; from 1 year to 10 years it is smaller by a factor of from 2 to 7. Such variations in predicted energy release rate for a given level of contamination would have a sufficiently great effect on the problems of passive defense against fallout, in assessing the significance of induced activities in weapons of reduced fission yield, and in estimating the fraction of fission activity contained in local and global fallout that it is considered worth examining the literature both for the basis of the estimates given in "The Effects of Nuclear Weapons" and for any subsequent independent evaluations of fission product gamma energy release rates.

Although no references are given in "The Effects of Nuclear Weapons," the rules and information given there are evidently based primarily on a paper prepared by Way and Wigner in 1945 and later published in Physical Review (vol. 73, p. 1318, June 1948). This 13-page paper, called "The Rate of Decay of Fission Products" gives a theoretical derivation of the combined gamma and beta activity and energy radiation rates following fission by treating the fission products as "a sort of statistical assembly." The paper is based largely on a semiempirical formula for the energy differences between isobars as a function of mass number, and a rough empirical fifth power relation between the half lives and disintegration energies of fission products. The theoretical results are compared with a tabulation of experimental results obtained in the wartime atomic energy project, and it is concluded that the comparison is fairly good. Explicit numerical conclusions are given for the combined gamma and beta energy radiation rates from fission products and for beta activity for times between  $10^{-3}$  seconds and 1,000 days.

An explicit Way-Wigner representation of the gross gamma photon energy release rate is found in an abstract of a paper presented to the American Physical Society at Chicago in June 1946 (recorded on p. 115 of vol. 70 of the Physical Review, July 1946).

According to that abstract—

"... the radioactivity which follows a number of fissions is thus made up of a number of individual activities of many periods and energies. The energy emitted per second per fission at time  $t$  after a fission is given by

$$\int_0^{\lambda_{max}} \lambda n(\lambda, t) E(\lambda) d\lambda$$

where  $n(\lambda, t)$  is the number of nuclei of decay constant  $\lambda$  existing at time  $t$  after a fission. Evaluation of this expression gives, for times greater than 1 day, the result

$$\text{Mev/sec/fission} = 3.75t^{-1.2} + 96t^{-1.4}$$

where  $t$  is measured in seconds. For shorter times a curve is given. This is the total energy emitted, including that carried by neutrinos. Agreement with experimental results is fairly good. Handy rules of thumb giving correct values within a factor of two for times between 10 seconds and 100 days are

$$\beta + \gamma; \text{Mev/sec/fission} = 2.66t^{-1.2}$$

$$\gamma; \text{Mev/sec/fission} = 1.26t^{-1.2}$$

"The total disintegration energy per fission turns out to be  $22 \pm 3$  Mev."

<sup>2</sup> USNRDL-TR-160, "Proposed Decay Schemes for Some Fission Products and Other Radionuclides," C. E. Miller, May 27, 1957. Unclassified.

<sup>3</sup> USNRDL-TR-187, "Gamma Decay of Fission Products From the Low Neutrons Fission of U-235," C. E. Miller, July 11, 1957. Unclassified.

<sup>4</sup> USNRDL-TR-247, "Ionization Rate and Photon Pulse Decay of Fission Products From the Slow Neutron Fission of U-235," C. E. Miller, P. Loeb, Aug. 4, 1958. Unclassified.

The expression

$$\text{Mev/sec/fission} = 1.26t^{-1.2} \quad (t \text{ in seconds})$$

is equivalent to

$$\text{Mev/sec}/10^4 \text{ fissions} = .68t^{-1.2} \quad (t \text{ in hours}),$$

so that the  $\gamma$  energy radiation rates predicted by this formula are uniformly 17 percent greater than those obtained from "The Effects of Nuclear Weapons."

In a summary of the wartime experimental results on the rate of gamma energy radiation from fission products given in their 1948 Physical Review paper, Way and Wigner list three experimental results which apply to time intervals of interest in fallout research. As given in Physical Review, vol. 73, page 1329, these results are:

|                                        | Function of time (t)<br>after fission (t in<br>seconds) | When valid              | References                                                                                                            |
|----------------------------------------|---------------------------------------------------------|-------------------------|-----------------------------------------------------------------------------------------------------------------------|
| $\gamma$ energy in Mev./fission/sec. = | $1.90t^{-1.2}$                                          | 10 seconds to 1 day...  | S. Kutchoff, B. Finkle,<br>N. Elliot, J. Knight,<br>N. Sugarman, Metallurgical Laboratory,<br>CC-1128, Dec. 11, 1943. |
|                                        | $4.2t^{-1.2}$                                           | 20 minutes to 3 days... | L. Borst, Metallurgical Laboratory, CI-697 VIII, C4.                                                                  |
|                                        | $49.0t^{-1.4}$                                          | 50 to 100 days...       |                                                                                                                       |

Expressed in Mev./sec./ $10^4$  fissions for  $t$  measured in hours, these expressions become, respectively:

|        | Function of time (t)<br>after fission (t in<br>seconds) | When valid              | References         |
|--------|---------------------------------------------------------|-------------------------|--------------------|
| 1..... | $0.49t^{-1.2}$                                          | 10 seconds to 1 day...  | (Sugarman et al.). |
| 2..... | $1.19t^{-1.2}$                                          | 20 minutes to 3 days... | (Borst).           |
| 3..... | $4.8t^{-1.4}$                                           | 50 to 100 days...       | Do.                |

The first of these formulas give a result uniformly lower than computations based on information from "The Effects of Nuclear Weapons." The second and third formulas (Borst) compare as follows:

Various estimates of  $\gamma$  Mev./sec./ $10^4$  fissions

|                                       | Time after fission    |                       |
|---------------------------------------|-----------------------|-----------------------|
|                                       | 1 hour                | 3 days                |
| Borst (formula No. 2).....            | 1.18                  | 0.0046                |
| "The Effects of Nuclear Weapons"..... | .58                   | .0034                 |
| NRDL.....                             | 1.31                  | .0042                 |
|                                       | 50 days               | 100 days              |
| Borst (formula No. 3).....            | $2.19 \times 10^{-4}$ | $0.82 \times 10^{-4}$ |
| "The Effects of Nuclear Weapons"..... | $1.17 \times 10^{-4}$ | $.51 \times 10^{-4}$  |
| NRDL.....                             | $1.63 \times 10^{-4}$ | $.6 \times 10^{-4}$   |

It is seen that the Borst experimental results for times between 1 hour and 3 days are in closer agreement with the NRDL computations than with information provided in "The Effects of Nuclear Weapons." For times between 50 and 100 days, the Borst experimental results are about as far above those of the NRDL as those derived from "The Effects of Nuclear Weapons" are below.

It should be noted the Borst results here tabulated are for a formula developed (presumably by Borst) to fit his experimental measurements and not the measurements themselves. The reference to Borst's work given by Way and Wigner is not available here in AEC headquarters. There is a comment in

a paper by Perkins and King (discussed later) to the effect that their theoretical derivations are in close agreement with the results of Borst and that "the detailed points given by Borst (to which the straight line is an approximation) follow the theoretical variations even more closely."

There have been several computations of gross energy release rates from fission products since the work of Way and Wigner in addition to those made by the NRDL. All are based on various compilations of the yields of the nucleus produced in fission and on their known or estimated decay schemes. One of the latest of these (in which many references to other work are given) is "Energy Release From the Decay of Fission Products," by J. F. Perkins and R. W. King, published in the June 1958 edition of Nuclear Science and Engineering. According to the authors:

"We have used the latest information on fission yields; in particular we used Pappas' modification of the equal charge displacement hypothesis which takes into account shell effects. We employ the same gamma energy groups as Motreff and Clark, and extend our calculations to shorter shutdown times by estimating spectra of those fission activities whose spectra have not been measured. Finally, and most significantly, we have tried to get the best possible information on decay schemes. In this effort we have had access to the latest work (as of July 1957) of the Nuclear Data Group of the National Research Council."

The Perkins-King data for gross gamma energy radiation rates are given for times between  $10^1$  and  $6 \times 10^7$  seconds so that it is possible to compare their results with those of the NRDL and "The Effects of Nuclear Weapons" over a period of from 1 hour to almost 2 hours. The results are shown in table 1.

A second paper entitled "The Activity of the Fission Products of  $U^{235}$ ," dated October 31, 1958, by Knabe and Putnam, and published by the Aircraft Nuclear Propulsion Division of General Electric, extends the work of Perkins and King to both shorter and somewhat longer times after fission (1 to  $10^6$  seconds), with the rate at shorter times based on experimental work by Zobel and Love at Oak Ridge (ORNL-2081, p. 95). These results are also shown in table 1. The Knabe-Putnam results generally agree with those of the NRDL, a little better than the Perkins-King results, but all three are in close agreement and differ significantly from the rates based on the  $t^{-1.2}$  decay and other data from "The Effects of Nuclear Weapons."

In converting from gamma energy release rates per unit area to external gamma dose rates in roentgens per hour, there are some additional differences between the results obtained by the NRDL and those based on "The Effects of Nuclear Weapons" which will not be considered here (see USNRDL-TR 247). The dose rates and integrated doses from 1 hour obtained by each method are given in table 2. These dose rates are those which would apply at 3 feet above a smooth infinite plane uniformly contaminated to a level of 1 kiloton of fission products per square mile. In using them for most practical problems, one must also take into account the reductions in dose rate which would take place due to partial shielding provided by terrain roughness and the gradual leaching of the radioactive particles down into the soil. The differences in roentgen dose rates shown in table 2 are more pronounced than indicated by the differences in energy release rate shown in table 1.

The significance of the gross gamma energy radiation rate from fission products for fallout analysis indicates the desirability of direct measurements of this quantity. Since fissions occurring in weapons are caused by neutrons with a broad range of energies and may occur in  $Pu^{239}$  and  $U^{235}$  as well as in  $U^{238}$ , the gamma radiation rate from fission products in weapons debris may deviate significantly from that due to the thermal fission of  $U^{235}$ . Consequently, next to measurements of the energy release rates from samples of weapons debris, it would be most useful to have results from the laboratory fission of  $U^{235}$ ,  $Pu^{239}$ , and  $U^{238}$  by neutrons with energies similar to those causing fission in typical weapons.

Although the open field roentgen dose rates will be approximately proportional only to the gamma energy radiation rate and not to the spectrum of the emitted energy, the spectrum is important in determining the effectiveness of different degrees and types of shielding, so that one is presumably also interested in the energy spectrum for each of the fissionable materials and for neutron energies representative of those causing fission in weapons. Only measurements on actual debris, however, can determine whether or not the energy emission rates and energy spectra are altered by fractionation of isotopes and to what extent such alterations take place. It should be noted that measurements on actual debris are complicated by the presence of neutron-induced activities from

both weapon and earth materials. The exact contribution of these induced activities from air and surface bursts to the external roentgen dose rate are not now well understood, although it appears that they should not be neglected.  $Np^{237}$ ,  $U^{237}$ ,  $U^{236}$ ,  $Na^{24}$ , and  $Mn^{54}$  may account for a substantial fraction of the open field roentgen dose delivered by local fallout from some high yield weapons between 8 hours and 1 week.

TABLE 1.—Gamma energy radiation rate from fission products (Mev/sec/ $10^4$  fissions)

| Time      | Release rates                                |                               |                              |                              | Ratio of results NRDL/ENW |
|-----------|----------------------------------------------|-------------------------------|------------------------------|------------------------------|---------------------------|
|           | From effects of nuclear weapons <sup>1</sup> | From NRDL-TR-187 <sup>2</sup> | By Perkins-King <sup>1</sup> | By Knabe-Putnam <sup>1</sup> |                           |
| 1 minute  | 80                                           | 1.31                          | 1.1                          | 1.2                          | 2.3                       |
| 1 hour    | 58                                           | 1.31                          | 1.1                          | 1.2                          | 2.1                       |
| 2 hours   | $2.52 \times 10^{-1}$                        | $5.30 \times 10^{-1}$         | $4.4 \times 10^{-1}$         | $5.0 \times 10^{-1}$         | 1.7                       |
| 6 hours   | $6.76 \times 10^{-2}$                        | $1.17 \times 10^{-1}$         | $1.1 \times 10^{-1}$         | $1.2 \times 10^{-1}$         | 1.8                       |
| 12 hours  | $2.94 \times 10^{-2}$                        | $5.22 \times 10^{-2}$         | $4.4 \times 10^{-2}$         | $4.4 \times 10^{-2}$         | 1.6                       |
| 1 day     | $1.28 \times 10^{-2}$                        | $2.00 \times 10^{-2}$         | $1.7 \times 10^{-2}$         | $1.7 \times 10^{-2}$         | 1.4                       |
| 36 hours  | $7.89 \times 10^{-3}$                        | $1.10 \times 10^{-2}$         | $1.0 \times 10^{-2}$         | $1.0 \times 10^{-2}$         | 1.3                       |
| 2 days    | $6.57 \times 10^{-3}$                        | $7.10 \times 10^{-3}$         | $7.0 \times 10^{-3}$         | $7.0 \times 10^{-3}$         | 1.2                       |
| 3 days    | $3.42 \times 10^{-3}$                        | $4.20 \times 10^{-3}$         | $4.0 \times 10^{-3}$         | $4.0 \times 10^{-3}$         | 1.3                       |
| 1 week    | $1.24 \times 10^{-3}$                        | $1.67 \times 10^{-3}$         | $1.5 \times 10^{-3}$         | $1.5 \times 10^{-3}$         | 1.5                       |
| 10 days   | $8.06 \times 10^{-4}$                        | $1.17 \times 10^{-3}$         | $1.1 \times 10^{-3}$         | $1.1 \times 10^{-3}$         | 1.5                       |
| 2 weeks   | $5.39 \times 10^{-4}$                        | $8.20 \times 10^{-4}$         | $8.0 \times 10^{-4}$         | $8.0 \times 10^{-4}$         | 1.5                       |
| 1 month   | $2.22 \times 10^{-4}$                        | $3.40 \times 10^{-4}$         | $3.4 \times 10^{-4}$         | $3.4 \times 10^{-4}$         | 1.2                       |
| 3 months  | $5.80 \times 10^{-5}$                        | $6.90 \times 10^{-5}$         | $7.6 \times 10^{-5}$         | $7.5 \times 10^{-5}$         | 0.96                      |
| 6 months  | $2.49 \times 10^{-5}$                        | $2.80 \times 10^{-5}$         | $2.6 \times 10^{-5}$         | $2.3 \times 10^{-5}$         | .46                       |
| 1 year    | $1.10 \times 10^{-5}$                        | $4.90 \times 10^{-6}$         | $5.0 \times 10^{-6}$         | $5.0 \times 10^{-6}$         | .14                       |
| 2 years   | $4.77 \times 10^{-6}$                        | $6.60 \times 10^{-6}$         | .....                        | $7.4 \times 10^{-7}$         | .13                       |
| 3 years   | $2.93 \times 10^{-6}$                        | $3.75 \times 10^{-6}$         | .....                        | $2.3 \times 10^{-7}$         | .14                       |
| 5 years   | $1.59 \times 10^{-6}$                        | $2.18 \times 10^{-6}$         | .....                        | .....                        | .24                       |
| 10 years  | $6.91 \times 10^{-7}$                        | $1.68 \times 10^{-6}$         | .....                        | .....                        | .81                       |
| 30 years  | $1.86 \times 10^{-7}$                        | $1.13 \times 10^{-6}$         | .....                        | .....                        | .79                       |
| 60 years  | $8.12 \times 10^{-8}$                        | $6.40 \times 10^{-7}$         | .....                        | .....                        | .70                       |
| 100 years | $4.38 \times 10^{-8}$                        | $3.06 \times 10^{-7}$         | .....                        | .....                        | .....                     |

<sup>1</sup> Based on the  $t^{-1.2}$  law, average gamma photon energy = 7 Mev, 1 kt = 300 megacuries gamma activity at 1 hr. (no indication whether slow or fast fission of  $U^{235}$ ,  $Pu^{239}$  or  $U^{238}$ ).

<sup>2</sup> Thermal neutron fission  $U^{235}$ .

TABLE 2.—Comparison of gamma dose rates and integrated doses for uniform contamination level of 1 kiloton of fission products per square mile

| Time after detonation | Dose rate (r/hr 3 feet above infinite plane) |                       |                | Integrated dose from 1 hour (roentgens) |             |
|-----------------------|----------------------------------------------|-----------------------|----------------|-----------------------------------------|-------------|
|                       | Effects of nuclear weapons                   | NRDL-TR-247           | Ratio NRDL/ENW | Effects of nuclear weapons              | NRDL-TR-247 |
| 1 hour                | 1,260                                        | 3,360                 | 2.7            | 0                                       | 0           |
| 2 hours               | 549                                          | 1,416                 | 2.6            | 815                                     | 2,199       |
| 6 hours               | 147                                          | 317                   | 2.2            | 1,898                                   | 4,766       |
| 12 hours              | 84                                           | 142                   | 2.2            | 2,467                                   | 5,950       |
| 24 hours              | 28                                           | 55                    | 2.0            | 2,964                                   | 7,012       |
| 48 hours              | 12.1                                         | 20.2                  | 1.7            | 3,407                                   | 7,803       |
| 3 days                | 7.43                                         | 11.52                 | 1.6            | 3,629                                   | 8,163       |
| 1 week                | 2.70                                         | 4.56                  | 1.7            | 4,042                                   | 8,831       |
| 2 weeks               | 1.17                                         | 2.21                  | 1.9            | 4,333                                   | 9,357       |
| 1 month               | .483                                         | .902                  | 1.9            | 4,612                                   | 9,898       |
| 2 months              | .294                                         | .329                  | 1.6            | 4,826                                   | 10,297      |
| 3 months              | .126                                         | .197                  | 1.6            | 4,939                                   | 10,481      |
| 6 months              | .0547                                        | .0792                 | 1.4            | 5,122                                   | 10,750      |
| 1 year                | .0238                                        | .0137                 | .58            | 5,273                                   | 10,911      |
| 2 years               | .0104                                        | .00185                | .18            | 5,399                                   | 10,952      |
| 3 years               | .00637                                       | .00108                | .17            | 5,475                                   | 10,965      |
| 5 years               | $3.45 \times 10^{-3}$                        | $6.24 \times 10^{-4}$ | .18            | 5,457                                   | 10,979      |
| 10 years              | $1.50 \times 10^{-3}$                        | $4.80 \times 10^{-4}$ | .32            | 5,657                                   | 11,002      |
| 30 years              | $6.52 \times 10^{-4}$                        | $3.04 \times 10^{-4}$ | .63            | 5,735                                   | 11,040      |
| 60 years              | $4.01 \times 10^{-4}$                        | $3.28 \times 10^{-4}$ | .81            | 5,782                                   | 11,073      |
| 80 years              | $1.75 \times 10^{-4}$                        | $1.82 \times 10^{-4}$ | 1.04           | 5,847                                   | 11,136      |
| 100 years             | $9.46 \times 10^{-5}$                        | $9.12 \times 10^{-5}$ | .96            | 6,080                                   | 11,183      |

## BIOGRAPHICAL MATERIAL

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## FALLOUT IN THE OCEANS

A statement prepared for the Special Subcommittee on Radiation, Joint Committee on Atomic Energy, Congress of the United States for public hearings on fallout from nuclear weapons tests, May 5-8, 1959

(By A. Seymour, Laboratory of Radiation Biology, University of Washington, May 4, 1959)

## INTRODUCTION

The following discussion of fallout in the oceans is, for the most part, a discussion of local, not stratospheric fallout. Local fallout is defined as the fallout that occurs during the first day or two following the detonation of a nuclear device and within a few hundred miles of ground zero. Local fallout differs from stratospheric fallout in several important aspects.

In an area of local fallout the amount of fallout per unit area and the size of the fallout particles are considerably greater than in an area of stratospheric fallouts only. For a surface explosion 85 to 85 percent of the fallout may be local and for an underwater detonation local fallout may be even greater. Also, the chemical form and the percentage composition of the radioisotopes in the two areas may differ. For the megaton weapons fired in the Pacific, the bulk of the fallout resides on particles of  $\text{CaO}$  or  $\text{Ca(OH)}_2$ , or mixtures of  $\text{CaO}$ ,  $\text{Ca(OH)}_2$ , and  $\text{CaCO}_3$  made by the great heat of the fireball acting on the coral of the islands and sea floor. A large amount also is carried on  $\text{NaCl}$  particles (Libby, 1958). The large particles of these compounds fall out locally and do

not enter the stratosphere. As a consequence greater quantities and different species of radioisotopes are found in a local fallout area as compared to an area with stratospheric fallout only.

In the following statement the order of presentation will be to discuss, first, the information about fallout in the ocean that has become available since the 1957 hearings and, secondly, the areas of future research.

The basic concept of the ability of marine plants and animals to concentrate from the ocean certain radioisotopes of fallout remains unchanged. Additional information since 1957 as a result of the analyses of more samples and of a more thorough search for the radioisotopes that are difficult to detect has led to the confirmation of some of the previous conclusions and to a modification of other conclusions. The comparison of results of radiological analyses cannot be made superficially and requires that careful consideration be given to the following three factors: (1) the completeness of the analysis; (2) the time after fallout when the collection was made and when the analysis was done; and (3) the similarity of samples as to species and tissue.

The completeness of analysis depends to a great extent upon the capability of the detecting equipment and the selection of the proper radiochemical method. As no one instrument or single method of radiochemical analysis is adequate to determine the presence of all radioisotopes the presence of a radioisotope, even in large amounts, may escape detection unless a combination of various methods is used. For example, the predominate radioisotope in the first analysis of the kidney of a giant clam from the Marshall Islands was found to be radiocobalt. However, a radioisotope of iron ( $\text{Fe}^{59}$ ), which emits a weak X-ray (see table 1) was present but was not detected by the original gamma spectrum analysis. When the proper technique for identifying  $\text{Fe}^{59}$  was used, radioiron was found to be in greater abundance than radiocobalt (table 2). Another example is that of the "Taney" plankton. Gamma spectrum analysis of a sample in November 1957 confirmed the earlier finding that the major fission products were  $\text{Ce}^{144}$ ,  $\text{Pr}^{144}$  but also revealed an appreciable amount of  $\text{Co}^{60}$  (Lawman, et al., 1958). Modification of techniques to meet the special requirements of an analysis are sometimes required. In order to accurately determine  $\text{Sr}^{90}$  in marine organisms, especially fish, a special technique was developed by Kawabata and Held (1958). As these special techniques develop and the detection equipment becomes more sensitive, more isotopes can be expected to be found or to be determined more accurately.

The time after fallout when the sample is collected demands consideration when the results of radiological analyses are being compared because the relative composition of the radioisotopes in a sample of mixed fission products is constantly changing (table 1). It is obvious that the comparison of the relative radioisotopic composition of two samples has little meaning unless the age of the radioisotopes in the samples are approximately the same.

TABLE 1.—Percent abundance of fission products,<sup>1</sup> radiation energy, half life, critical organ, and maximum permissible concentration of fallout radioisotopes of biological interest

|                    | Percent abundance at— <sup>1</sup> |         |        |          | Radiation energy, Mev <sup>2,3</sup> |       | Half life <sup>2,4</sup> |                         | Critical organ <sup>2</sup> | MPC<br>μCi/ml. <sup>2,5</sup> |
|--------------------|------------------------------------|---------|--------|----------|--------------------------------------|-------|--------------------------|-------------------------|-----------------------------|-------------------------------|
|                    | 1 week                             | 1 month | 1 year | 10 years | Beta                                 | Gamma | Physical                 | Biological<br>(for man) |                             |                               |
| Fission products:  |                                    |         |        |          |                                      |       |                          | Days                    |                             |                               |
| Sp <sup>235</sup>  | 2.1                                | 6.7     | 2.7    |          | 1.46                                 | None  | 51 days                  | 3,900                   | Bone                        | 0.00007                       |
| Sr <sup>90</sup>   |                                    |         | 1.8    | 21.8     | 0.54                                 | do.   | 28 years                 | 3,900                   | do.                         | 0.000008                      |
| Y <sup>90</sup>    |                                    |         | 1.8    | 21.8     | 2.25                                 | Weak  | 64 hours                 | >500                    | do.                         | 2                             |
| Zr <sup>90</sup>   | 2.4                                | 7.6     | 3.9    |          | 1.54                                 | 1.22  | 58 days                  |                         |                             |                               |
| Nb <sup>90</sup>   | 2.3                                | 8.2     | 7.3    |          | 0.36                                 | 0.72  | 65 days                  |                         |                             |                               |
| Ru <sup>106</sup>  |                                    | 4.1     | 15.0   |          | 0.16                                 | 0.76  | 35 days                  |                         | Bone                        | .004                          |
| Rh <sup>106</sup>  |                                    |         | 2.4    |          | 0.04                                 | None  | 1 year                   |                         | Kidneys                     | .1                            |
| I <sup>131</sup>   | 6.3                                | 3.7     |        |          | 3.5                                  | 0.51  | 30 seconds               |                         | Thyroid                     | .00003                        |
| Cs <sup>137</sup>  |                                    |         | 1.5    | 18.2     | 0.61                                 | 0.36  | 8.1 days                 |                         | Muscle                      | .0016                         |
| Ba <sup>140</sup>  |                                    |         | 1.5    | 18.2     | 1T                                   | 0.66  | 27 years                 |                         |                             |                               |
| Ba <sup>140m</sup> | 8.8                                | 10.8    |        |          | 1.02                                 | 0.03  | 2.6 minutes              |                         | Bone                        | .002                          |
| La <sup>140</sup>  | 9.4                                | 12.5    |        |          | 1.36                                 | 0.33  | 13 days                  |                         | do.                         | 1                             |
| Ce <sup>144</sup>  |                                    | 2.0     | 29.5   |          | 0.31                                 | 0.03  | 40 hours                 |                         | do.                         | .04                           |
| Pr <sup>144</sup>  |                                    | 2.0     | 26.5   |          | 2.97                                 | 0.06  | 285 days                 |                         | do.                         | 1                             |
| Pm <sup>147</sup>  |                                    |         | 5.7    | 15.8     | 0.22                                 | Weak  | 17 months                |                         | do.                         |                               |
| Total              | 31.5                               | 57.6    | 99.0   | 95.8     |                                      |       | 2.6 years                |                         |                             |                               |
| Mn <sup>54</sup>   |                                    |         |        |          | EC                                   | 0.84  | 290 days                 | 5                       | Liver                       | .0013                         |
| Fe <sup>55</sup>   |                                    |         |        |          | EC                                   | None  | 2.6 years                | 65                      | Blood                       | .005                          |
| Fe <sup>59</sup>   |                                    |         |        |          | 0.46                                 | 1.1   | 45 days                  | 65                      | do.                         | .0061                         |
| Co <sup>60</sup>   |                                    |         |        |          | EC                                   | 0.12  | 270 days                 | 8                       | Liver                       | .0072                         |
| Co <sup>57</sup>   |                                    |         |        |          | B <sup>+</sup> =0.47                 | 0.81  | 71 days                  | 8                       | do.                         | .0015                         |
| Co <sup>58</sup>   |                                    |         |        |          | 0.31                                 | 1.17  | 5.2 years                | 23                      | do.                         | .02                           |
| Zn <sup>65</sup>   |                                    |         |        |          | B <sup>+</sup> =0.32                 | 1.12  | 250 days                 | 23                      | Bone                        | .06                           |

<sup>1</sup> Maximum permissible concentration in drinking water based on the assumption that water consumption is 2,200 ml. per day and that water is the only source of radiological contamination. Values can be directly extrapolated to grams of food when compensation is made for the difference between the daily intake of water and food.

<sup>2</sup> Hunter and Ballou, 1951.

<sup>3</sup> Strominger, et al., 1959.

<sup>4</sup> Kinsman, 1967.

<sup>5</sup> NBS Handbook No. 52, 1953.

<sup>6</sup> Lowman, 1957.

<sup>7</sup> And others.

TABLE 2.—The radioisotopic composition of plankton, algae, clams, and fish from the Central Pacific in the vicinity of the Eniwetok test site  
(Percent of radioactivity of total sample)

|                                                                              | Sample No. | Thousands<br>of d/m/g | Mn <sup>54</sup> | Fe <sup>55</sup> | Fe <sup>59</sup> | Co <sup>60</sup> | Co <sup>57</sup> | Co <sup>58</sup> | Zn <sup>65</sup> | Sr <sup>90</sup> | Sr <sup>89</sup> | Y <sup>90</sup> | Zr <sup>90</sup> | Nb <sup>90</sup> | Ru <sup>106</sup> | Rh <sup>106</sup> | Ru <sup>106m</sup> | Cs <sup>137</sup> | Ba <sup>140</sup> | La <sup>140</sup> | Ce <sup>144</sup> | Pr <sup>144</sup> | Pm <sup>147</sup> | W <sup>187</sup> | Others |
|------------------------------------------------------------------------------|------------|-----------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|-----------------|------------------|------------------|-------------------|-------------------|--------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|------------------|--------|
| Plankton:                                                                    |            |                       |                  |                  |                  |                  |                  |                  |                  |                  |                  |                 |                  |                  |                   |                   |                    |                   |                   |                   |                   |                   |                   |                  |        |
| Samples: "Marsh"                                                             | 7 to 9     | 75                    | <1               | 19               | 0                | 10               | 15               | 1                | 18               | 0                | 0                | 0               | 25               |                  |                   |                   |                    |                   |                   |                   |                   |                   |                   |                  |        |
| Area: at sea, Eniwetok to Guam                                               | 13 to 15   | 29                    | <1               | 19               | 0                | 8                | 14               | 1                | 14               | 0                | 0                | 0               | 44               |                  |                   |                   |                    |                   |                   |                   |                   |                   | 5                 |                  |        |
| Date: Sept. 1-20, 1956                                                       | 43 to 46   | 108                   | <1               | 13               | 0                | 16               | 26               | 1                | 17               | 0                | 0                | 0               | 12               |                  |                   |                   |                    |                   |                   |                   |                   |                   | 13                |                  |        |
| Radioactivity: Total as disintegrations per minute per gram of ashed sample. | 50 to 53   | 127                   | <1               | 28               | 0                | 6                | 11               | 1                | 32               | 0                | 0                | 0               | 14               |                  |                   |                   |                    |                   |                   |                   |                   |                   | 8                 |                  |        |
| Samples: "Collette"                                                          | 57 to 59   | 48                    | <1               | 39               | 0                | 5                | 6                | 1                | 44               | 0                | 0                | 0               | 6                |                  |                   |                   |                    |                   |                   |                   |                   |                   |                   |                  |        |
| Area: at sea, Eniwetok to Guam                                               | 2          | 718                   |                  | 0                | 1                | 8                | 40               | 3                | 12               | 0                | 0                | 0               | 5                |                  |                   |                   |                    |                   |                   |                   |                   |                   |                   |                  |        |
| Collection: Aug. 8-14, 1958                                                  | 3          | 16,127                |                  | 4                | <1               | 1                | 5                | <1               | 0                | 0                | 0                | 0               | 2                |                  |                   |                   |                    |                   |                   |                   |                   |                   |                   |                  |        |
| Radioactivity: d/m/g dry weight                                              | 4          | 2,318                 |                  | 24               | 1                | 6                | 24               | 4                | 0                | 0                | 0                | 0               | 2                |                  |                   |                   |                    |                   |                   |                   |                   |                   |                   |                  |        |
| Algae:                                                                       | 36         | 2,680                 |                  | 4                | <1               | 3                | 16               | 1                | 0                | 0                | 0                | 0               | 2                |                  |                   |                   |                    |                   |                   |                   |                   |                   |                   |                  |        |
| Halimeda: Eniwetok, Belle; July 22, 1956                                     | 1,600      |                       |                  |                  |                  | <1               | <1               | <1               |                  |                  |                  | 32              | 7                |                  |                   | 31                |                    |                   |                   |                   |                   |                   |                   |                  |        |
| Caulerpa: Eniwetok, Vera; June 25, 1958                                      | 321        |                       |                  |                  |                  | 0                | 0                | 0                |                  |                  |                  |                 | 72               |                  | 6                 |                   |                    |                   |                   |                   |                   | 13                |                   | 7                |        |
| Udotea: Bikini, Nan; Aug. 28, 1958                                           | 29         |                       |                  |                  |                  | 0                | 0                | 0                |                  |                  |                  |                 | 32               |                  | 12                |                   |                    |                   |                   |                   |                   | 37                |                   | 0                |        |
| Invertebrates:                                                               |            |                       |                  |                  |                  |                  |                  |                  |                  |                  |                  |                 |                  |                  |                   |                   |                    |                   |                   |                   |                   |                   |                   |                  |        |
| Clam kidney: Eniwetok, Belle; Sept. 22, 1956; d/m/g wet weight               | I          | 1,600                 | 2                | 74               | <1               | 10               | 9                | 2                | 0                | 0                | <1               | 3               | <1               |                  |                   | 1                 |                    | 0                 |                   |                   |                   |                   | 0                 |                  |        |
| Tridacna (clam) visceral mass; Eniwetok, Vera; Sept. 27, 1958                | 376        |                       |                  |                  |                  | 1                | 5                | <1               | 0                |                  |                  |                 | 22               |                  | 72                |                   |                    |                   |                   |                   |                   | 0                 |                   | 0                |        |
| Fish:                                                                        |            |                       |                  |                  |                  |                  |                  |                  |                  |                  |                  |                 |                  |                  |                   |                   |                    |                   |                   |                   |                   |                   |                   |                  |        |
| Liver homogenate; Bikini, How; Sept. 22, 1956; d/m/g wet weight              | II         | 18                    | 6                | 15               | 0                | 8                | 4                | 7                | 58               | 0                | 0                | 0               | 0                |                  |                   | 0                 |                    | 0                 |                   |                   |                   |                   | 0                 |                  | <1     |
| Bonita liver; Bikini, Fox; Sept. 23, 1956; d/m/g wet weight                  | III        | 30                    | 2                | 56               | <1               | 3                | 1                | 3                | 35               | 0                | 0                | 0               | <1               |                  |                   | 0                 |                    | 0                 |                   |                   |                   |                   | 0                 |                  | 1      |
| Liver homogenate; Eniwetok, Belle; May-June 1954                             | IV         | 48                    | 1                | 96               | 0                | <1               | 0                | 1                | 3                | 0                | 0                | 0               | 0                |                  |                   | 0                 |                    | 0                 |                   |                   |                   |                   | 0                 |                  | <1     |
| Reef fish liver; Allingine Atoll; July 11, 1957; d/m/g wet weight            |            | 2                     | 1                | 26               |                  | 22               | 4                | 3                | 40               |                  | 0                |                 |                  |                  |                   |                   |                    |                   |                   |                   |                   |                   |                   |                  | 6      |
| Flying fish muscle; August 1958; d/m/g dry weight                            |            | 15                    |                  | 0                | 1                | 2                | 11               | 1                | 84               |                  |                  |                 | <1               |                  | <1                |                   |                    |                   |                   |                   |                   |                   |                   |                  |        |
| Flying fish liver; August 1958; d/m/g dry weight                             |            | 236                   |                  | 0                | 13               | 6                | 32               | 2                | 47               |                  |                  |                 | <1               |                  | <1                |                   |                    |                   |                   |                   |                   |                   |                   |                  |        |
| Surgeon fish liver; Bikini, Nan; Aug. 28, 1958                               |            | 38                    |                  |                  |                  | 10               | 45               | 2                | 43               |                  |                  |                 | 0                |                  | 0                 |                   |                    | 0                 | 0                 |                   |                   |                   |                   | 0                |        |

<sup>1</sup> Lowman, 1958.

<sup>2</sup> Lowman, et al., 1959.

<sup>3</sup> Palumbo, 1959.

<sup>4</sup> Gamma emitters only.

<sup>5</sup> Lowman, et al., 1957.

<sup>6</sup> Unknown anions.

<sup>7</sup> Welander, 1958.



Thirdly, the comparison of results of analyses may require that the samples be alike as to species, tissue, and even physiological function. Using the giant clam again as an example, there are species living in the tropical Pacific that acquire a large portion of their food by growing and harvesting *Zooxanthellae* within their own body. These clams have a large and specialized kidney which concentrates radiocobalt to a high degree. There are other giant clams in the Pacific that are not as dependent upon *Zooxanthellae* and do not have as specialized a kidney. In the clams with the less specialized kidney more radiocobalt is found than radiocobalt and this finding is in agreement with laboratory experiments with less specialized clams (Chipman, 1958). Thus it would be inaccurate to make a generalization about the uptake of fallout radioisotopes by clams based upon the analysis of the unusual kidney of a highly specialized species which is common and important in only a limited part of the world.

The comparison of results of radiological analysis of marine organisms may be used to evaluate the health hazard to man associated with eating certain sea foods. (Man's concern about fallout in the ocean is primarily as to how it will affect his health and secondarily as to how it will affect his ocean resources). The health hazard problem will not be discussed here, other than to say that to evaluate hazard, it is equally important to know both the amount and the species of radioisotope present. The variation in MPC values as given in table 1 (the difference between  $Sr^{90}$  and  $Pm^{147}$  is greater than 1 million) points out the futility of estimating hazard without knowing the radioisotopes present, a practice that has been followed on occasion in the past.

Although it was stated above that most of the observations on fallout in the ocean have been of close-in fallout, the Woods Hole Oceanographic Institution is studying the distribution of five fallout radioisotopes— $Sr^{90}$ ,  $Sb^{125}$ ,  $Cs^{137}$ ,  $Ce^{144}$ , and  $Pm^{147}$ —in the Atlantic Ocean, an area far removed from close-in fallout. Because the amount of these radioisotopes in Atlantic Ocean waters is minute, large samples and special separation methods are required and the number of samples processed is relatively small. The minute weight of fallout that is added to the ocean can be determined by calculating the amount of an isotope in terms of weight units rather than in units of radioactivity. Using  $Sr^{90}$  as an example and assuming that the radioactivity from  $Sr^{90}$  is 30 disintegrations per minute per 100 liters of water—the highest value found in the Atlantic (Bowen and Sugihara, 1957)—the amount of  $Sr^{90}$  in the 100 liters of water is calculated to be  $10^{-14}$  grams. Since there is 1 gram of stable strontium in 100 liters of water the dilution of the stable strontium by the radioactive strontium is of the order of 1 part in 10 trillion. Therefore, it is evident that although the presence of a radioisotope from fallout can be detected easily by radiological methods the weight of the isotope is much less than can be detected by the most sensitive balance.

For certain areas of the Atlantic Ocean the amount of  $Sr^{90}$  delivered per unit area of sea surface has been calculated from the determination of  $Sr^{90}$  in the surface layer and the depth of that layer. From analyses of the 1956 and 1957 data the amount of  $Sr^{90}$  in the surface waters was generally greater than for land areas at comparable latitudes (Libby, 1956) and varied by a factor of five between extremes (Bowen and Sugihara, 1957). The  $Sr^{90}$  values for surface waters from the shelf area were the highest of any area and ranged from 8.3 to 30.0 disintegrations per minute per 100 liters of water. Begeman and Libby (1957) report the same general sort of variation in the analyses of Atlantic water for bomb tritium. Further study will indicate whether the fivefold variation of  $Sr^{90}$  in surface waters is an artifact or the result of some factor in the circulatory system that prevents the surface waters from becoming thoroughly mixed. In deep ocean water, below 800 meters, the values for  $Sr^{90}$  were less than 10 percent of the surface values.

Selection of the other four radioisotopes— $Sb^{125}$ ,  $Cs^{137}$ ,  $Ce^{144}$ , and  $Pm^{147}$ —was based on the fact that their relatively long half lives and relatively high yields in fission gave promise that detectable amounts would be found, and that their chemical behavior was well enough known to permit a meaningful analysis of the data when obtained (Bowen and Sugihara, 1958). Too few samples have been analyzed so far to permit a reliable interpretation of the results.

Although  $Sr^{90}$  may be more abundant in the Pacific Ocean in the vicinity of the Eniwetok test site than in the Atlantic Ocean the occurrence of  $Sr^{90}$  in the marine organisms of the Pacific is not common. The low levels of radiostrontium in fish and other marine organisms was pointed out in the 1957 hearings (Alexander, 1957; Revelle, 1957) and has been substantiated by additional analyses

since that time. If radiostrontium is present in the marine biological samples it is usually in the samples collected during the first few days after fallout when many of the other fission products that are not found in samples collected at a later time are also present. The presence of a broad array of fission products in the samples immediately after fallout is believed to be at least partially, an adsorption phenomena. Radioisotopes are present in particulate form immediately after fallout and when in this form the most effective concentrators of activity are the mucous, ciliary, and pseudopodial filterers (Schaefer, 1957). Lowman (1958) is also in agreement with the postulate that the major source of radioactive elements from fallout to marine zooplankton is through the uptake of particulate material.

In marine organisms collected a few weeks, months, or years after fallout at a time when radiostrontium and other long-lived fission products would be expected to be present, radiostrontium has not been detected by the techniques used or is present at extremely low levels (table 2). For conditions of equal fallout the  $Sr^{90}$ -calcium ratio which is the important factor in determining the hazard from  $Sr^{90}$  is a good deal less for pelagic fish than in such calcium-rich terrestrial food products as milk (Schaefer, 1958).

Although radiostrontium may not be present in marine organisms collected in the vicinity of the Eniwetok test site, radiostrontium is found in some of the plants and animals living on the atolls in the same area. From the limited information available at the time of the 1957 hearings the inference was made that the plants and animals living on the coral atolls would not be expected to concentrate radiostrontium because of the high calcium content of the soils, a situation similar to that which occurs in the ocean. However, this is not true, as some land plants and animals do accumulate  $Sr^{90}$  in measurable amounts, especially the coconut crabs (Heid, 1957). Although calcium is abundant in the soils, apparently only part of the calcium is in a chemical form which is available to the plants. This is a difficult matter to resolve in a quantitative manner but efforts are continuing in that direction. Other radioisotopes that have been found in soil samples but not in marine organisms are antimony-125 and europium-155 (Palumbo and Lowman, 1958).

On page 526 of the report of the 1957 hearings the suggestion was made that the concentration of various radioactive substances in different parts of marine organisms should be considered because there are marked differences and in the case of some marine organisms not only the flesh but the skin, viscera, and bones are eaten. The data on one fish that was given is now supplemented by the results of counting 633 specimens collected over a period of 19 months at Eniwetok Atoll (Welander, 1957). The average values by tissues for beta radioactivity based on the percent of total radioactivity for the tissues counted are as follows:

|         | [In percent] |
|---------|--------------|
| Skin    | 8            |
| Muscle  | 1            |
| Bone    | 8            |
| Liver   | 23           |
| Viscera | 60           |

Surveys to determine the geographical and biological distribution of fallout in the ocean during and after Operation Hardtack in 1958 were carried out in a similar fashion to the surveys for Operation Redwing in 1956 (Donaldson, 1956; Seymour, 1957). Plankton continues to be the most sensitive indicator of radioactivity in the sea with concentration factors ranging from 1,000 to several thousand.

The distribution of fallout in the sea a month after the conclusion of the testing program can be defined from the radioactivity in the plankton samples. The rate of movement can only be approximated because the origin of the fallout at any one sampling station is not known accurately in respect to either time or area. The origin may be any of many detonations that occur during the testing period which lasts for several months and for which the area of the original local fallout is only known within several hundred miles. In 1956, fallout, as indicated by the radioactivity of the plankton samples, was 800 miles west of Eniwetok 1 month after the end of the Redwing series, but it is to be remembered that this fallout could have originated several months earlier at the beginning of the Redwing series. In 1958, at a comparable time in respect to the end of the test series, fallout was detectable in the plankton 1,100 miles west of Eni-

wetok. The best estimate of the westward rate of advance is about 10 miles per day or slightly less. In 1958 a surface drague placed a few miles west of Eniwetok moved 51 miles in 71 hours, or about 17 miles per day. This rate of movement was for a short distance and is a measure of the surface current which would be expected to be faster than the rate of advance of fallout as measured by the radioactivity in plankton.

Radiochemical separations by ion exchange and precipitation techniques and gamma spectrum analyses were used to determine the radioisotopes present in the plankton samples. For the Redwing samples, fission products, mainly  $Zr^{90}$ - $Nb^{90}$  and  $Ce^{138}$ - $Pr^{140}$ , contributed an average of 20 percent of the total radioactivity. The remaining 71 percent was contributed by the nonfission radioisotopes  $Zn^{65}$ ,  $Co^{60}$ ,  $Fe^{59}$ , and  $Mn^{54}$ . Radioactive zinc, cobalt, and iron accounted for averages of 24, 20, and 21 percent, respectively, of the total radioactivity, and  $Mn^{54}$  was present in trace amounts (Lowman, 1958). The results of analysis of four of the samples is given in table 2.

In the Hardtack plankton samples the presence of radioactive tungsten ( $W^{187}$ ) was striking. Plankton samples with  $W^{187}$  were found in three areas and contributed as much as 83 percent of the total radioactivity. Plankton taken outside of these areas did not contain radiotungsten nor was it found in any plankton samples collected 3 weeks later in the same area, corrected for the rate of advance, where  $W^{187}$  was found originally (Lowman, 1959). The assumption based on this and other evidence is that tungsten occurred as an external contaminant and that little was taken up biologically. The analyses of four of the 1958 plankton samples are also given in table 2. The 1958 plankton sample was a fresher fallout material which accounts in part for the difference in the radioisotopic composition between the 1956 and 1958 plankton samples.

From the measurement of the radioactivity in plankton, fish, and other organisms in the sea, it is evident that the organisms, especially plankton, play an important role in the translocation and movement of radioisotopes in the sea. The ability of plankton organisms to rapidly acquire a large part of the radioactivity in the sea and to make diurnal vertical migrations from the relatively fast moving and well-mixed surface layer of the ocean to the slow-moving stratified water layers of the deeper ocean has been demonstrated. A study of the fundamental processes involved in the translocation of radioisotopes by a plankton population has been initiated and a report of the state of progress of this research was given at the second Geneva Conference on the peaceful uses of atomic energy (Ketchum and Bowen, 1958).

In addition to the analyses to determine the radioisotopes present in plankton, similar analyses have been made of algae, clams, fish, and many of the land plants and some of the land animals. A few of the analyses for algae, clams, and fish are given in table 2. The results as given in the table are comparable from one sample to another only in a general way because the specimens have been collected from areas that have received fallout at various times ranging from a few days to 10 years. Although the analyses of the land plants and animals is not given there is a striking difference between the land and the sea in the biological distribution of the fission products and nonfission products (transition elements). In general the transition elements iron, zinc, cobalt, and manganese are present in marine animals but in very low amounts when present in marine plants or on the land. None of the radioactive transition

elements or only low levels are present in island soil, in plants growing in the soil, or in the herbivorous field rats. However, in the plankton, the marine invertebrate filter feeders and omnivores, and in the fishes, the transition elements may contribute up to 100 percent of the total radioactivity.

Other observations on the biological uptake of radioisotopes are as follows: Of the long-lived fission product isotopes— $Sr^{90}$ ,  $Cs^{137}$ , and  $Ce^{144}$ —only  $Ce^{144}$  enters into the biological cycle in the marine environment to a significant extent. However, on land,  $Sr^{90}$  and  $Cs^{137}$  are taken up but  $Ce^{144}$  is not to any great extent.

Of the gamma-emitting isotopes present in 10 tissues of reef and lagoon fish the radioisotopic composition did not vary greatly from tissue to tissue except that radiocobalt was not found in the bone. Practically no fission products were found in fish. The transition elements ranked in order of abundance are radioiron, zinc, cobalt, and manganese. Oceanic fish differ from reef and lagoon fish in that radiozinc ranks first in abundance in the former.

In comparison with fish, plankton have greater amounts of radiocobalt and lesser amounts of radioiron.

In order to be able to predict the future levels of radioactivity in the plants and animals of the Eniwetok test site area the rate of decline has been determined for many organisms. The rate of decline is defined as the rate at which the radioactivity is decreasing in a given tissue, organ, or organism in its native environment (Held, 1957). The only constant factor is that of physical decay. Prediction of rate of decline would be extremely difficult by other than empirical means. The decline rates and decay rates for many organisms in various areas in the vicinity of the Eniwetok test site are reported by Bonham (1958).

In general the decay curves are steeper than the decay curve for mixed fission products which is generally expressed as being  $t^{-1.2}$ . The mean of about 100 decay curves was about  $t^{-1.6}$ . The greatest deviation from the mean was for muscle samples from birds and rats for which the decay rate was much slower.

The decline rates were equal to or greater than the decay rate of  $t^{-1.2}$ . The difference between the decay rate for mixed fission products and the decay rate and decline rate of the biological samples means that the radioactivity is declining faster in plants and animals than it would from fallout that included the entire spectra of fission products. Reasons for this are that there is biological selectivity of the radioisotopes and other factors such as weathering. The decline in radioactivity of representative samples from just after the Nectar shot at Eniwetok in 1954 to a time 700 days later are given in table 3. That different tissues have different rates of decline is evidenced by the shift in relative positions of the samples in regard to radioactivity between the first and last collections.

Since the beginning of the series of weapons tests at Bikini and Eniwetok a program to determine the biological and geographical distribution of fallout in the vicinity of the test site has been a part of each test operation. The biological program of the laboratory of radiation biology, University of Washington (formerly the Applied Fisheries Laboratory) since the first operation at Bikini in 1946 has recently been reviewed by Donaldson (1959a). Other reports on radioactivity in the oceans and of biological programs associated with weapons testing programs are included in recent bibliographies by Davis (1958) and by Wallace (1958).

being  
declining  
from  
Figure 2  
Hemisphere  
curve



Table 3. Decline in radioactivity of samples collected at Eniwetok immediately following and 700 days after the Nectar Shot, May 14, 1954.

| Maximum value 1-3 days post Nectar | 700 days post Nectar     |
|------------------------------------|--------------------------|
| d/m/g wet                          | d/m/g wet                |
| Plankton                           |                          |
| Bird feathers and skin             |                          |
| Algae                              |                          |
| Snail liver                        |                          |
| Clam visceral mass                 |                          |
| " kidney                           |                          |
| Beach sand                         |                          |
| Fish gut                           |                          |
| Bird gut                           |                          |
| Sea cucumber gut                   |                          |
| Bird bone, kidney                  |                          |
| Coral                              |                          |
| Bird liver, lung                   |                          |
| Fish skin, bone                    |                          |
| Sea cucumber muscle                |                          |
| Snail muscle                       |                          |
| Clam muscle                        |                          |
| Sea water                          |                          |
| Fish muscle                        |                          |
|                                    | Snail liver              |
|                                    | Clam kidney              |
|                                    | Beach sand               |
|                                    | Snail muscle             |
|                                    | Fish liver               |
|                                    | Plankton                 |
|                                    | Fish gut                 |
|                                    | Sea cucumber gut         |
|                                    | Clam visceral mass       |
|                                    | Bird kidney, liver, lung |
|                                    | Sea cucumber muscle      |
|                                    | Fish bone                |
|                                    | Algae                    |
|                                    | Clam muscle              |
|                                    | Bird bone, skin          |
|                                    | Coral                    |
|                                    | Fish skin                |
|                                    | Fish muscle              |
|                                    | Bird muscle              |
|                                    | Bird gut                 |
|                                    | Sea water                |

The fallout at Rongelap Atoll has received special attention. This is the one area in the world where fallout has been great enough to require that the population be evacuated. Although the level of radioactivity is now low and the natives can live safely at Rongelap, the area provides a wonderful opportunity for a study of radioisotopes in a natural environment. The history of the Rongelap studies follow.

Since the radioactive contamination of Rongelap Atoll on March 1, 1954, repeated studies have been made of the extent and distribution of the contamination. Eleven collections were made by the laboratory of radiation biology, University of Washington, between March 1954 and March 1959, and two collections by the Naval Radiological Defense Laboratory, February 1955 and February 1956. Analyses of some of the samples were made by the Health and Safety Laboratory of the Atomic Energy Commission. In addition, teams of medical experts have

been conducting periodic medical examinations of the Rongelapese. The soils and biological monitoring data through 1956 have been summarized by Dunning (1957).

It was recognized that while monitoring of the biota for radioactive contamination is essential to an immediate estimate of potential hazards, the information so gained is limited in application. Understanding of the processes involved in the movement of radioisotopes throughout the physical and biological system of the atoll are essential if it is hoped to arrive at basic conclusions of broader applicability. From such basic conclusions it might then be possible to predict the consequences of future contamination of similar areas and possibly the development of practical methods of reducing radioisotopic levels in foods of the area. It was also recognized that the total ecology of the area should eventually be understood in as great detail as possible in order to understand the processes by which the radioisotopes move from the soil to plants and probably to the sea, from the lagoon bottom to the marine life and sea birds, thence back to the land. Obviously this is an ambitious concept involving many disciplines. The implementation of such concept deserves careful consideration of the area to be studied. Rongelap Atoll has a unique advantage since it has been contaminated only once by moderately high levels of fallout. Thus the time of origin is known without the confusion due to repeated contamination of the same area. There is what might be thought of as a disadvantage, the fact that atolls are not typical of continental situations. On the other hand, a glance at a map of the Pacific Ocean quickly shows that a large portion of the earth's surface is represented by atolls and other coralline islands.

Late in 1958 the University of Washington, Laboratory of Radiation Biology under the direction of Prof. Lauren R. Donaldson was asked to institute a program of radiation ecology at Rongelap Atoll. The first expedition was made in March 1958 in cooperation with a medical team headed by Dr. Robert A. Conrad of the Brookhaven National Laboratories. Since that time trips have been made in August-September 1958 by the ecology group and March 1959 by the medical and ecology groups.

It should be emphasized that radiation effects on the biota are too elusive to be profitably followed in the field. Deleterious effects are produced by a variety of agents which are not all known and are difficult to separate under field conditions. It has never been possible to determine with certainty that observed abnormalities of the biota in the vicinity of the Eniwetok test site have been due to radiation effects. Indeed, the same abnormalities have been found in areas not subject to radioactive contamination. Consequently, studies aimed specifically at the determination of radiation effects can best be done under controlled laboratory conditions.

The emphasis at Rongelap Atoll has therefore been on mineral transport through the biota. This requires evaluation of the stable isotopes as well as the radioisotopes. The efforts of the first year have been concentrated on the land forms; however, collection and analysis of marine organisms have been made to provide a continuous record of radiation levels in different life forms. The marine phase is to be expanded during the coming year to include more extensive sampling of the lagoon bottom and waters.

None of the studies can be considered complete now or for some time to come. Some of the points that stand out most clearly thus far are as follows:

1. The general levels of radioactivity continue to decline more rapidly than would be expected from physical decay alone (there are certain exceptions such as the levels of  $\text{Sr}^{90}$  in coconut crabs.)
2. Extensive sampling of soils shows clearly that the radioisotopes remain concentrated in the top inch or less.
3. Radioactive materials are found more uniformly mixed to a depth of several inches in lagoon sediments.
4. Collection of rain water which has percolated through undisturbed soil shows that  $\text{Cs}^{137}$ ,  $\text{Ru}^{106}$ ,  $\text{Rh}^{106}$ ,  $\text{Zr}^{95}$ ,  $\text{Nb}^{95}$ ,  $\text{Sb}^{125}$ , and  $\text{Ce}^{144}$  are being leached from the soil in very small but as yet undetermined amounts.
5.  $\text{Cs}^{137}$  is the principal long-lived fission product taken up by the plants. The  $\text{Cs}^{137}$  levels are higher in older leaves than in younger leaves.
6. There is a general potassium deficiency in the area. Fertilization experiments indicate that the potassium levels are associated with  $\text{Cs}^{137}$  uptake by the plants.

7. Variation in all types of soil and biological samples is commonly as great as by a factor of five for a given type sample taken in an area of less than one square mile.

8. Evaluation of calcium levels in the soil in terms of absolute levels of available calcium is very difficult. It is clear that although these are highly calcareous soils, available calcium represents a small fraction of the total calcium. This is important relative to  $\text{Sr}^{90}$  uptake.

9. In general  $\text{Cs}^{137}$  and  $\text{Sr}^{90}$  are the principal long-lived isotopes found in the land organisms while  $\text{Zn}^{65}$ ,  $\text{Co}^{60}$ ,  $\text{Mn}^{54}$  and  $\text{Fe}^{59}$  are found in the marine organisms.

The need for future studies on fallout in the ocean are in general similar to the needs for studies in the ocean related to the disposal of high level radioactive wastes. The Committee on Oceanography for the National Academy of Sciences has recommended a program in oceanography for the years 1960-70. Part of the program is for the study of radioactivity and has been planned with the expectation that the oceans may be used as a disposal area for high level radioactive wastes. The section on "Radioactivity in the Ocean" from chapter 1 of the report by the Committee on Oceanography of the National Academy of Sciences (1959) is included as an appendix to this report. Fulfillment of the recommended program also would provide answers to questions regarding fallout in the ocean.

A study that is in process and will be reported in the near future is the radiological analysis of 2,700 tuna samples from the western Pacific that were collected before, during and after the Hardtack series (Donaldson, 1959b).

The presence of fallout in the ocean provides a unique opportunity to study basic biological and physical processes in the sea. The addition of radiolabeled tracers to the ocean, especially in the vicinity of Eniwetok test site during a weapons testing program, provides tracers for the study of mineral metabolism and transport, or of the movement of ocean currents, or other important research problems. Fallout in the ocean provides a tool for a large scale field experiment that cannot be duplicated elsewhere.

The assistance of Dr. Edward Held in the preparation of this report is acknowledged with pleasure.

#### SUMMARY--FALLOUT IN THE OCEAN

The concepts on the uptake and concentration of fallout by marine organisms that were presented at the 1957 hearings are basically unchanged. The greatest emphasis of recent studies has been to identify all of the radiolabeled isotopes in the samples.

The following observations in an area of local fallout, the Eniwetok test site, have been made:

(1) Of the three long-lived fission products,  $\text{Cs}^{137}$ ,  $\text{Sr}^{90}$ , and  $\text{Ce}^{144}$ , only the latter is found in marine organisms. (If present,  $\text{Sr}^{90}$  occurs at low levels); by contrast  $\text{Cs}^{137}$  and  $\text{Sr}^{90}$  are found in land forms while  $\text{Ce}^{144}$  generally is not.

(2) Of the nonfission product radiolabeled isotopes of iron, zinc, cobalt, and manganese were predominant in marine animals but were much less abundant in marine plants, land plants, and land animals.

Radiostromium as stratospheric or possibly intermediate fallout has been measured in the Atlantic Ocean. The data so far available indicates an amount in surface water greater than predicted but the significance of the difference is questionable because of the limited number of samples.

The program at Rongelap Atoll has been enlarged to include basic studies of mineral transport and metabolism in addition to radiation monitoring.

The presence of fallout in the ocean provides a unique opportunity to study basic biological and physical processes in the sea. It is recommended that a research program be planned to take advantage of this opportunity.

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#### APPENDIX

##### RADIOACTIVITY IN THE OCEANS<sup>1</sup>

The widespread use of nuclear energy for peaceful or military purposes necessitates studies to determine the effects of radioactive contamination upon the oceans and the life therein. The Committee on Effects of Atomic Radiation on Oceanography and Fisheries in its report to the National Academy of Sciences made certain general recommendations concerning national policy in this area. Both the Committee on Oceanography and the Committee on Effects of Atomic Radiation on Oceanography and Fisheries believe that more specific and detailed recommendations can now be made.

1. A single agency should be given the overall responsibility and authority for regulating the introduction of radioactive materials in the oceans. Monitoring of disposal sites should be done by some agency other than the regulating agency. It is recommended that either the Coast and Geodetic Survey or the Public Health Service be made responsible for engineering studies in and near disposal areas, for routine monitoring of disposal areas and their surroundings and for a continuing assessment of the effects on the environments of added radioactive materials.

2. Vigorous programs should be started for the purpose of determining the circulation and mixing processes which control the dispersion of introduced contaminants in coastal and estuarine environments and in the open ocean. These studies represent the major part of the proposed budget in this area.

3. A program should be pursued aimed at determining the inorganic transfer of radioactive elements from sea water to the sediments.

4. Studies should be made of the effects of living organisms on the distribution of radioactive elements introduced into the sea.

5. The genetic effects of radiation upon marine organisms should be studied.

6. A variety of biological field experiments should be conducted utilizing radioisotopes.

7. The proposed budgets for the programs are given in tables 12 and 13. The greater part of the program should be financed by the Atomic Energy Commission.

<sup>1</sup> See "Literature Cited" (21).

TABLE 12.—Radioactivity in the oceans—Summary of budget estimates

(Annual cost in 1958 dollars)

|                                                                                                               | Without ship time | Ship time | Total     |
|---------------------------------------------------------------------------------------------------------------|-------------------|-----------|-----------|
| Control and monitoring                                                                                        | \$70,000          |           | \$70,000  |
| Estuarine and coastal studies                                                                                 | 1,220,000         | 880,000   | 2,100,000 |
| Research in open ocean                                                                                        | 1,000,000         | 400,000   | 1,400,000 |
| Sedimentation processes                                                                                       | 449,000           | 35,000    | 484,000   |
| Effects of the biosphere                                                                                      | 678,000           | 280,000   | 958,000   |
| Genetic effects                                                                                               | 100,000           |           | 100,000   |
| Biological field experiments                                                                                  | 100,000           |           | 100,000   |
| Total, 1st year                                                                                               | 4,617,000         | 1,575,000 | 6,192,000 |
| Total subsequent years                                                                                        | 4,432,000         | 1,375,000 | 5,807,000 |
| About one-third is now underway.                                                                              |                   |           |           |
| Net cost of new program: 1st year                                                                             | 3,078,000         | 1,450,000 | 4,528,000 |
| Subsequent years                                                                                              | 2,954,000         | 1,050,000 | 4,004,000 |
| If 2 large open sea tests are conducted, 1 in 1962 and 1 in 1966, the additional costs in those years will be | 1,400,000         | 600,000   | 2,000,000 |
| Total in those years                                                                                          | 4,354,000         | 1,650,000 | 6,004,000 |

<sup>1</sup> \$264,000 after 1st year.

<sup>2</sup> \$299,000 after 1st year.

(Table 13 not included here.)

#### BIOGRAPHY

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(To be submitted to Science)

#### RADIOCARBON FROM NUCLEAR TESTS

(Wallace S. Broecker and Alan Walton\*)

As a result of the generation of neutrons in nuclear tests and their subsequent reaction with nitrogen in the atmosphere, considerable manmade  $C^{14}$  has been added to the earth's dynamic carbon reservoir. On the basis of the measured neutron yield per unit energy release and on the assumption that about two-thirds of the  $C^{14}$  produced falls back as calcium carbonate, Libby (1) has estimated that  $10 \times 10^{21}$   $C^{14}$  atoms have been introduced into the atmosphere. Rafter and Fergusson (2) have shown that the  $C^{14}$  concentration in southern hemisphere tropospheric  $CO_2$  has been increasing at 2.1 percent per year since 1955. In the northern hemisphere de Vries (3) has suggested an increase of 4.3 percent between 1953 and 1957. Results of Munnich and Vogel (4) point to an increase of about 3.2 percent per year for central Europe and 2 percent per year in South Africa over the period from 1954 to 1957. Considerable interest has been aroused in the possible genetic effects of this increase in the  $C^{14}$  concentration, the potential hazards having been reviewed by Leipunsky (5) Pauling (6) Sakharov (7) and Totter et al. (8). Recent data obtained by the authors relating to this increase are presented in this paper together with a brief discussion of the probable distribution of bomb  $C^{14}$  within the dynamic carbon reservoir.

\*This research was carried out at the Lamont Geological Observatory, Columbia University. Dr. Broecker is a member of the staff of the Columbia University Geology Department and Dr. Walton is presently a staff member of the National Physical Laboratory, Teddington, England.

## RESULTS

The general rise in the concentration of  $C^{14}$  in atmospheric  $CO_2$  has been monitored by direct measurement of the  $C^{14}/C^{12}$  ratio in samples of atmospheric  $CO_2$  as well as by measurement of plant material which recently has fixed atmospheric  $CO_2$ . In order to make these measurements directly comparable, all the results are normalized to a common  $C^{13}/C^{12}$  ratio. This eliminates any differences created by isotopic fractionation during the photosynthetic process, during the collection of atmospheric  $CO_2$  or during the chemical processing of samples in the laboratory.

The results are summarized in table 1.  $\delta C^{14}$  represents the age-corrected per mil difference in the radioactivity of the sample  $CO_2$  gas from that of a standard

$$\delta C^{14} = \frac{A^* \text{ sample} - 0.950 A^0 \text{ oxalic standard}}{0.950 A^0 \text{ oxalic standard}} \times 1000 \quad (A)$$

where  $A^*$  sample is the measured  $C^{14}$  activity of the sample corrected for radioactive decay during the period between sample formation and measurement and  $A^0$  oxalic standard is the  $C^{14}$  activity of the National Bureau of Standards  $C^{14}$  standard, corrected for radioactive decay between January 1, 1958, and the measurement date. The 0.950 factor is introduced so that the age-corrected values of wood grown during the 19th century fall close to zero on the scale. Activity measurements were made using the technique described by Broecker et al. (9) with errors based on reproducibility of the counting measurements rather than on radioactivity statistics alone.

Following Craig (10) the  $\delta C^{13}$  results are expressed as per mil difference from the Belemnite standard. The isotope ratio measurements were made with a Consolidated 401 double-collecting mass spectrometer on the  $CO_2$  gas used for the radioactivity measurement (11). The uncertainty in the  $\delta C^{13}$  results is about 1 per mil.

Normalization to a common  $C^{13}/C^{12}$  ratio is carried out as follows:

$$\Delta C^{14} = \delta C^{14} - 2 \delta C^{13} \left( 1 + \frac{\delta C^{13}}{1000} \right) - 50.0 \quad (B)$$

Again the constant term (-50.0) is introduced so that  $\Delta C^{14}$  for age-corrected 19th century wood falls close to zero on the scale (12).

The results from the Northern Hemisphere plotted against time in figure 1 suggest a general increase of about 50 per mil (5 percent) per year in the  $C^{14}$  concentration of atmospheric  $CO_2$  over the past 3 years. This is somewhat higher than the estimates given by de Vries (3) and by Munnich and Vogel (4). The spread of the points in figure 1 must be related at least in part to local release of large quantities of industrial  $CO_2$  (13). Consequently the curve has been drawn through points obtained on samples collected in areas removed from intense industrial activity (the Great Basin, the North Atlantic Ocean, and the Mediterranean Sea). The horizontal portion of this curve has been fixed by using Fergusson's value of minus 20 per mil for the average Suess effect (13). It is interesting to note that data obtained by Munnich and Vogel (4) on plant material from Germany in general show a smaller increase than the data defining the curve in figure 1. If plotted in figure 1 they would agree well with the data from Kearney, Palisades, and Rome.

The difference between the  $C^{14}$  concentration in leaf samples grown at Lamont and that in average Northern Hemisphere tropospheric  $CO_2$  appears to be increasing with time. Such an increase would not be expected if the difference were a result of a higher local Suess effect. The suggestion of Munnich and Vogel (4) that plants grown in areas of dense vegetation may take up an appreciable quantity of  $CO_2$  given off by adjacent soils provides a possible explanation for such a divergence. For since much of the  $CO_2$  given off by soils probably results from the decay of organic materials formed prior to bomb testing, the contrast between the  $C^{14}$  concentration in soil  $CO_2$  and that in atmospheric  $CO_2$  is increasing rapidly with time. In this connection it is of interest to note that the points defining the curve in figure 1 are all from areas of sparse vegetation and thus free from influence of soil  $CO_2$  as well as that of local industrial  $CO_2$ .

Figure 2 compares the Northern Hemisphere data of figure 1 with that published by Rafter and Fergusson (2) for the Southern Hemisphere. The Southern Hemisphere curve is drawn assuming that the Lamont and New Zealand 1890

wood standards have identical activities. Recent measurement of the New Zealand wood standard at Lamont supports this assumption (the New Zealand laboratory pre-1900 wood average is within 1 per mil of the value for the Lamont 1890 wood standard). The two added points represent Lamont data from the Southern Hemisphere. In the following paragraphs it is shown that the proximity of the two curves confirms Fergusson's (13) conclusion (based on the distribution of industrial  $CO_2$ ) that the mixing rate between the hemispheres must be quite rapid (i.e., less than 2 years).

## INTERHEMISPHERE MIXING

Since most of the bomb  $C^{14}$  is added to the stratosphere of the Northern Hemisphere, there are two possible modes of mixing between the hemispheres: mixing above the tropopause and below the tropopause. Two extreme cases may then be considered: (1) bomb  $C^{14}$  transfer from the Northern Hemisphere to the Southern Hemisphere dominantly in the stratosphere, and (2) transfer dominantly in the troposphere.

In the first case the rate of change in the number of bomb  $C^{14}$  atoms in the Southern Hemisphere troposphere ( $N_{ST}$ ) at any time  $t$  is given by:

$$\frac{dN_{ST}}{dt} = \lambda_1 N_{ST} \quad (C)$$

where  $\lambda_1$  is the mixing coefficient between the stratosphere and troposphere and  $N_{ST}$  is the number of bomb  $C^{14}$  atoms in the Southern Hemisphere troposphere. In words, this equation simply says that the rate at which the amount of tropospheric bomb  $C^{14}$  increases is directly proportional to the amount of bomb  $C^{14}$  in the stratospheric source. The troposphere is so much more massive than the stratosphere that the return flux of  $C^{14}$  to the stratosphere is neglected in equation (C). In the case of intrastratospheric transfer, however, both directions are important so that the equation defining the rate of increase in the Southern Hemisphere stratosphere is as follows:

$$\frac{dN_{SS}}{dt} = N_{ST} \lambda_2 - N_{SS} \lambda_2 \quad (D)$$

where  $\lambda_2$  is the stratosphere mixing coefficient between the Northern and Southern Hemispheres and  $N_{SS}$  is the number of bomb  $C^{14}$  atoms at any given time in the Northern Hemisphere stratosphere. An equation similar to (C) can be written for the stratosphere-to-troposphere transfer in the Northern Hemisphere:

$$\frac{dN_{NT}}{dt} = \lambda_1 N_{NT} \quad (E)$$

Since the rate of increase,  $dN_{NT}/dt$ , is proportional to the slope of the curve in figure 2 and since this slope is approximately constant after early 1955,  $dN_{NT}/dt$  is set equal to a constant,  $B$ . Again the return flux as well as any loss of bomb  $C^{14}$  to the ocean or biosphere are neglected (see below).

Simultaneous solution of the above equations yields

$$N_{ST} = Bt - \frac{B}{\lambda_2} (1 - e^{-\lambda_2 t}) \quad (F)$$

It is assumed that at time zero (i.e., March 1955) all the  $N$  terms are zero. Since  $N_{NT} = Bt$ , it follows that

$$\frac{N_{ST}}{N_{NT}} = 1 - \frac{1}{\lambda_2 t} (1 - e^{-\lambda_2 t}) \quad (G)$$

From figure 2 the Southern Hemisphere tropospheric bomb  $C^{14}$  concentration was 0.70 times that in the Northern Hemisphere in September 1958—that is, at  $t = 3.5$  years,  $N_{ST}/N_{NT} = 0.70$ . Substitution of these values in equation (G) shows  $\lambda$  to be about 1.0. Since the reciprocal of  $\lambda_2$  is mean residence time, the average bomb  $C^{14}$  atom spends about 1 year in the Northern Hemisphere stratosphere before entry into the Southern Hemisphere stratosphere.

In the second extreme case, bomb radiocarbon travels to the Southern Hemisphere solely through the troposphere. The equation defining the rate of increase of Southern Hemisphere tropospheric bomb  $C^{14}$  has the form of equation (D), as follows:

$$\frac{dN_{ST}}{dt} = N_{NT} \lambda_3 - N_{ST} \lambda_3 \quad (H)$$

When combined with the previously used relationship,  $N_{NT} = Bt$ , and integrated, equation (H) becomes identical to (F) except that  $\lambda_2$  replaces  $\lambda_1$ . Similarly, equation (G) will represent case 2 if  $\lambda_2$  replaces  $\lambda_1$ . This means that the reciprocal of  $\lambda_2$ , the mean residence time of a bomb  $C^{14}$  atom in the Northern Hemisphere troposphere, is also about 1 year. Although somewhat lower this value is consistent with that of 1.5 years based on a similar calculation by Munnich and Vogel (4).

The model on which these results are based is admittedly oversimplified, for among other things no attempt was made to take into account direct addition of bomb  $C^{14}$  to the Southern Hemisphere during tests carried out near the equator or in the Southern Hemisphere itself. Consequently it can only be said that mixing between the hemispheres is sufficiently rapid that either the entire stratosphere or the entire troposphere mixes horizontally with a mean mixing time of less than 2 years. From the bomb  $C^{14}$  data alone it is impossible to determine whether the rapid mixing occurs above, below, or possibly both above and below the tropopause.

#### QUANTITY AND DISTRIBUTION OF BOMB $C^{14}$

Two major questions next arise: (1) What is the total quantity of bomb  $C^{14}$  added to the dynamic carbon cycle up to March 1958? and (2) if no more bomb  $C^{14}$  were added after March 1958, how would the bomb  $C^{14}$  concentration in the atmosphere change with time?

The answer to the first question requires not only a knowledge of the amount of bomb  $C^{14}$  in the troposphere but also the amounts which have entered the ocean and the terrestrial biosphere as well as the amount still stored in the stratosphere.

If complete mixing within each hemisphere is assumed the amount of bomb  $C^{14}$  in the troposphere can be estimated directly from figure 2 and a knowledge of the prebomb tropospheric  $C^{14}$  inventory ( $25 \times 10^{21}$  atoms). Up to March 1958 the amounts are  $1.5 \times 10^{21}$  atoms of bomb  $C^{14}$  in the Southern Hemisphere troposphere and  $2.1 \times 10^{21}$  atoms for the Northern Hemisphere.

The amount of bomb carbon which has entered the terrestrial biosphere can be estimated in the following manner. The rate of change of bomb  $C^{14}$  in the biosphere may be written as

$$\frac{dN_B}{dt} = \frac{R_P N_T}{N_T} - N_B \lambda_{B-T} \quad (I)$$

where  $N_T$  and  $N_B$  are the number of bomb  $C^{14}$  atoms in the troposphere and biosphere at any given time  $t$ ,  $N_T$  is the number of stable carbon atoms in the troposphere,  $R_P$  is the rate of photosynthesis by terrestrial plants (i.e., atoms of carbon fixed per unit time) and  $\lambda_{B-T}$  is the average rate of decay of terrestrial plant material back to  $CO_2$  (i.e., atoms of carbon decaying per unit time per atom of biospheric carbon). Expressing  $N_T$  as  $B'$  where  $B'$  is the observed constant rate of increase in the number of atoms of bomb  $C^{14}$  in the total troposphere (Northern plus Southern Hemispheres), the following relationship results from integration of equation (I):

$$N_B = \frac{R_P B'}{N_T \lambda_{B-T}} \left[ t - \frac{1}{\lambda_{B-T}} (1 - e^{-\lambda_{B-T} t}) \right] \quad (J)$$

As before the increase rate  $B'$  is computed on the assumption that the bomb  $C^{14}$  concentration in the troposphere has increased at a linear rate since March 1955—an approximation sufficiently close to the actual situation that a significant error is not introduced. From figure 2,  $B' = 1.2 \times 10^{21}$  atoms/year. From Goldschmidt (14)  $R_P$  is about  $20 \times 10^{25}$  gm of carbon/year and  $1/\lambda_{B-T}$ , the mean life of carbon in the biosphere, is about 15 years. When these values are substituted into equation (J) the value of  $N_B$  turns out to be  $0.2 \times 10^{21}$  atoms. Since this is small compared to the bomb carbon entering other reservoirs, the relatively large uncertainties associated with  $R_P$  and  $1/\lambda_{B-T}$  are not critical to the overall inventory.

The amount of bomb  $C^{14}$  which has entered the ocean can be estimated from Craig's (15) value of mean residence time of  $CO_2$  in the atmosphere with respect to entry into the ocean. If the addition rate,  $A$ , of bomb  $C^{14}$  to the troposphere is considered constant (essentially true over the 3-year period from March 1955 to March 1958) and if loss of bomb  $C^{14}$  to the biosphere is neglected, then the number of bomb  $C^{14}$  atoms which have entered the ocean,  $N_o$ , up to time  $t$  is simply the difference between the total amount added to the troposphere,  $At$ , and the amount,  $N_T$ , in the troposphere at time  $t$ ; that is

$$N_o = At - N_T \quad (K)$$

When differentiated with respect to  $t$ , equation (K) becomes

$$\frac{dN_o}{dt} = A - \frac{dN_T}{dt} \quad (L)$$

The rate at which bomb  $C^{14}$  enters the ocean is assumed to be directly proportional to the amount of bomb  $C^{14}$  present in the troposphere and the return flux from ocean to atmosphere is considered negligible; therefore

$$\frac{dN_o}{dt} = \lambda_{T-o} N_T \quad (M)$$

where  $\lambda_{T-o}$  is the mixing coefficient for transfer of  $CO_2$  from troposphere to ocean. Combining equations (L) and (M) to eliminate  $N_T$  and integrating the result is

$$N_T = A/\lambda_{T-o} (1 - e^{-\lambda_{T-o} t}) \quad (N)$$

Substituting this result into (K),

$$N_o = At - \frac{A}{\lambda_{T-o}} (1 - e^{-\lambda_{T-o} t}) \quad (O)$$

Using the limits of .25 and .10  $yr^{-1}$  given by Craig (15) for  $\lambda_{T-o}$  and a value of  $A$  based on  $B'$  and an iterative correction for loss to the ocean upper and lower limits of  $1.5 \times 10^{21}$  and  $0.6 \times 10^{21}$  atoms of  $C^{14}$  are obtained for  $N_o$  with a most probable value of  $1.0 \times 10^{21}$  atoms. This indicates that only about one quarter of the bomb  $C^{14}$  added to the troposphere has entered the ocean.

If the bomb  $C^{14}$  that has entered the ocean were concentrated entirely in the upper 100 meters, the  $C^{14}/C^{12}$  ratio in average surface ocean bicarbonate should be from 12 to 32 per mil higher than in 1955. Table 2 summarizes actual measurements on samples from the surface of the north and equatorial Atlantic over the 2-year period between 1955 and 1957. Although the results suggest a small increase ( $\sim 15$  per mil) the uncertainties are sufficiently large that no precise estimate of the magnitude of the increase can be given. It appears, however, to be less than 30 per mil and is thus consistent with the calculated estimate. It should be noted that these calculations involve only the bomb  $C^{14}$  which is converted into  $CO_2$  and not that which falls into the ocean as  $CaCO_3$ . The fate of the latter is uncertain.

From this data the fraction of bomb  $C^{14}$  which has entered the ocean appears to be somewhat lower than that given by Munnich and Vogel (4) who based their estimate on the atmospheric  $CO_2$  residence time given by Rafter and Fergusson (2) (1.4 years) rather than the value of Craig (13) (7 years) used in this paper. The Rafter and Fergusson value is based on the 18 per mil increase

in  $C^{14}$  concentration of the dissolved bicarbonate in surface ocean water from Markara Bay off New Zealand over the period from November 1954 to May 1957. Both the further measurements by Rafter and Fergusson (2) which indicate no further rise over the period from May 1957 to March 1958 and the data on the Atlantic Ocean presented in this paper suggest that the 1.9 year value is not a reliable estimate.

The critical factor in the overall inventory is the amount of bomb  $C^{14}$  stored in the stratosphere. As pointed out by Libby (1) most H-bomb clouds rise well into the stratosphere and so it is reasonable to assume that most of the newly produced bomb  $C^{14}$  is added to this reservoir. In this case a minimum estimate of the amount stored in the stratosphere would certainly be obtained if the fractional increase in stratospheric  $C^{14}$  were assumed to be the same as that measured for the troposphere. Since the stratosphere contains only about 20 percent of the amount of  $CO_2$  in the troposphere, the minimum is thus  $0.7 \times 10^{21}$  atoms of  $C^{14}$ .

A maximum estimate can be made by taking the highest estimates of stratospheric residence time calculated for fission-product debris and by assuming that all bomb  $C^{14}$  added to the lower atmosphere comes down from the stratosphere. In this case:

$$N_s^* = \frac{A}{\lambda S - T} \quad (P)$$

where  $N_s^*$  is the number of bomb  $C^{14}$  atoms in the stratosphere,  $A$  is the addition rate of  $C^{14}$  to the troposphere from the stratosphere and  $\lambda_{S-T}$  is the transfer coefficient from stratosphere to troposphere. Again return flow can be neglected since the maximum residence time estimate is appreciably longer than the period of large-scale bomb testing. Using the value of  $A$  ( $1.5 \times 10^{21}$  atoms/year) computed in connection with equation (O) and 15 years as an upper limit for the mean stratospheric storage time (16) a value of  $22.5 \times 10^{21}$  atoms is obtained for an upper limit on  $N_s^*$ . If this is really the case, the amount of bomb  $C^{14}$  in the average mole of stratospheric  $CO_2$  must be about 30 times greater than that in each mole of tropospheric  $CO_2$ . Using the value of 5 years given by Machta (16) as the best estimate a value of  $7 \times 10^{21}$  atoms is obtained.

Summing the upper and lower limits for each reservoir, limits can be set on the total amount of bomb  $C^{14}$  added to the dynamic carbon reservoir through March 1958. The results as summarized in table 3 suggest an upper limit of  $28 \times 10^{21}$  and a lower limit of  $5 \times 10^{21}$  atoms (best estimate  $12 \times 10^{21}$  atoms). These may be compared with the estimate of  $10 \times 10^{21}$  atoms given by Libby (1) for the same period. The latter estimate is based on the neutron flux per megaton and the number of megatons exploded rather than on direct measurements of  $C^{14}$  concentration. Since there are at present about  $2,000 \times 10^{21}$  cosmic-ray produced  $C^{14}$  atoms in the dynamic reservoir, the bomb  $C^{14}$  represents a total increase of from 0.25 to 1.4 percent (best estimate 0.6 percent). Thus, complete mixing will result in a 50-fold reduction in the atmospheric bomb  $C^{14}$  concentration if the lower estimate is used and a 20-fold reduction if the upper value is used (assuming no further production by bombs).

An important question is: how long will the mixing process require? Since great uncertainties exist concerning (1) the rate of exchange between the stratosphere and troposphere, (2) the size and turnover rate of the biosphere, and (3) the patterns and rates of mixing in the deep ocean, precise estimates must await further work. A contribution to the third aspect is the extensive program currently being carried out at Lamont to determine mixing rates in the Atlantic Ocean (17). This investigation will be the subject of a separate paper.

#### CONCLUSIONS

The following conclusions can be drawn from the present study:

1. The  $C^{14}$  concentration in the tropospheric  $CO_2$  of the Northern Hemisphere has increased by about 5 percent per year between March 1955 and March 1958.
2. In order to account for the distribution of bomb  $C^{14}$  between the hemispheres sufficiently rapid horizontal mixing must exist that either the stratosphere or the troposphere or perhaps both are mixed with a mean time of less than 2 years.
3. Only about 10 percent of the bomb  $C^{14}$  produced up to March 1958 has entered the oceans.
4. Differences within one hemisphere appear to be related to local dilution with  $C^{14}$  deficient  $CO_2$ .

5. The total bomb  $C^{14}$  added to the dynamic carbon reservoir through March 1958 is between  $5 \times 10^{21}$  atoms and  $28 \times 10^{21}$  atoms. The range results largely from the uncertainty in the amount stored in the stratosphere.

6. When distributed uniformly throughout the dynamic reservoir, the bomb  $C^{14}$  produced through March 1958 will leave the atmosphere with a 0.25 to 1.41 percent higher  $C^{14}$  concentration than that of the prebomb era. This increment will then decay away with a half-life of 5,600 years.

7. Critical factors still to be determined are the residence time of gas molecules in the stratosphere and the rate of mixing between surface and deep oceans.

TABLE 1. - Data showing the rise in the  $C^{14}$  concentration of atmospheric  $CO_2$  as a result of nuclear testing

| Growth date    | Location <sup>1</sup>                                              | Material           | $\delta C^{14}$ | $\delta C^{13}$ | $\Delta C^{14}$ | Lamont No.           |
|----------------|--------------------------------------------------------------------|--------------------|-----------------|-----------------|-----------------|----------------------|
| 1875           | Pacific Northwest United States                                    | Spruce wood        | $0 \pm 6$       | $-21 \pm 4$     | $-7 \pm 6$      | L-383D.              |
| 1890           | Pallades, N.Y.                                                     | Oak wood           | $1 \pm 5$       | $-24 \pm 0$     | $0 \pm 5$       | L-314.               |
| 1938           | do                                                                 | do                 | $-29 \pm 5$     | $-24 \pm 1$     | $-32 \pm 5$     | L-313.               |
| 1954           | do                                                                 | Oak leaves         | $-17 \pm 6$     | $-23 \pm 2$     | $-21 \pm 5$     | L-316B.              |
| Pre-1955       | Lake Winnemere, Nev.                                               | Sage wood          | $4 \pm 7$       | $-11 \pm 2$     | $-23 \pm 7$     | L-288M.              |
| June 1956      | North Atlantic, latitude $34^\circ$ N., longitude $64^\circ$ W.    | Atmospheric $CO_2$ | $62 \pm 8$      | $-9 \pm 0$      | $31 \pm 8$      | L-367A.              |
| Do             | North Atlantic, latitude $32^\circ$ N., longitude $69^\circ$ W.    | do                 | $54 \pm 6$      | $(-8 \pm 4)$    | $(21 \pm 7)$    | L-367H.              |
| July 1956      | Mediterranean Sea, latitude $41^\circ$ N., longitude $13^\circ$ E. | do                 | $88 \pm 8$      | $-7 \pm 4$      | $54 \pm 8$      | L-367C.              |
| Do             | Mediterranean Sea, latitude $36^\circ$ N., longitude $23^\circ$ E. | do                 | $64 \pm 6$      | $-5 \pm 3$      | $25 \pm 6$      | L-367D.              |
| November 1956  | Rome, Italy                                                        | Poplar twigs       | $17 \pm 5$      | $-25 \pm 0$     | $18 \pm 5$      | L-471B.              |
| Do             | do                                                                 | Grain              | $23 \pm 6$      | $-25 \pm 1$     | $24 \pm 6$      | L-371A.              |
| October 1957   | Pallades, N.Y.                                                     | Leaves             | $53 \pm 7$      | $-25 \pm 6$     | $57 \pm 7$      | L-445.               |
| August 1957    | Kearney, Nebr.                                                     | do                 | $48 \pm 7$      | $-31 \pm 8$     | $65 \pm 7$      | L-415B.              |
| Do             | Evanston, Wyo.                                                     | do                 | $83 \pm 7$      | $-28 \pm 2$     | $94 \pm 7$      | L-415C.              |
| Do             | Oquirrh Mountain, Utah                                             | do                 | $89 \pm 7$      | $-26 \pm 0$     | $96 \pm 7$      | L-415E.F.            |
| Do             | Wadsworth, Nev.                                                    | do                 | $85 \pm 7$      | $-27 \pm 8$     | $95 \pm 7$      | L-415H.I.            |
| Do             | Truckee, Calif.                                                    | do                 | $91 \pm 7$      | $-27 \pm 2$     | $100 \pm 7$     | L-415Q.Q.            |
| November 1957  | North Atlantic, latitude $25^\circ$ N., longitude $56^\circ$ W.    | Atmospheric $CO_2$ | $131 \pm 7$     | $-10 \pm 8$     | $105 \pm 7$     | L-464 <sup>1</sup> . |
| December 1957  | North Atlantic, latitude $11^\circ$ N., longitude $35^\circ$ W.    | do                 | $109 \pm 6$     | $-7 \pm 2$      | $75 \pm 6$      | L-466J.              |
| January 1958   | South Atlantic, latitude $33^\circ$ S., longitude $50^\circ$ W.    | do                 | $94 \pm 9$      | $-8 \pm 8$      | $63 \pm 9$      | L-466C.              |
| February 1958  | South Atlantic, latitude $54^\circ$ S., longitude $64^\circ$ W.    | do                 | $103 \pm 6$     | $-13 \pm 1$     | $82 \pm 6$      | L-466D.              |
| October 1958   | Pallades, N.Y.                                                     | Leaves             | $77 \pm 5$      | $-27 \pm 0$     | $85 \pm 5$      | L-487S.              |
| September 1958 | Evanston, Wyo.                                                     | do                 | $142 \pm 7$     | $-23 \pm 7$     | $146 \pm 7$     | L-487H.              |
| Do             | Oquirrh Mountain, Utah                                             | do                 | $111 \pm 7$     | $-22 \pm 6$     | $111 \pm 7$     | L-487C.              |
| August 1958    | Wadsworth, Nev.                                                    | do                 | $131 \pm 9$     | $-26 \pm 1$     | $140 \pm 9$     | L-487D.              |
| Do             | Truckee, Calif.                                                    | do                 | $126 \pm 7$     | $-26 \pm 1$     | $135 \pm 7$     | L-487E.              |

<sup>1</sup> See (12) for exact latitude and longitude data.



TABLE 2.—Summary of  $C^{14}$  measurements on dissolved bicarbonate from the north and equatorial Atlantic surface waters

| NORTH ATLANTIC      |                   |                                 |                                      |                                |
|---------------------|-------------------|---------------------------------|--------------------------------------|--------------------------------|
| Collection date     | Number of samples | Average $\Delta C^{14}$ per mil | Standard deviation from mean per mil | Standard error of mean per mil |
| November 1955       | 8                 | -49                             | $\pm 6$                              | $\pm 3$                        |
| June 1956           | 4                 | -48                             | $\pm 9$                              | $\pm 5$                        |
| July 1957           | 1                 | -44 $\pm 7$                     |                                      |                                |
| October 1957        | 1                 | -23 $\pm 7$                     |                                      |                                |
| November 1957       | 4                 | -33                             | $\pm 12$                             | $\pm 6$                        |
| EQUATORIAL ATLANTIC |                   |                                 |                                      |                                |
| February 1956       | 2                 | -61                             | $\pm 7$                              | $\pm 5$                        |
| January 1957        | 2                 | -62                             | $\pm 13$                             | $\pm 9$                        |
| May 1957            | 1                 | -68 $\pm 7$                     |                                      |                                |
| December 1957       | 1                 | -48 $\pm 9$                     |                                      |                                |

TABLE 3.—Inventory of bomb produced  $C^{14}$  as of March 1958

|               | Troposphere<br>$N_T$ | Terrestrial Biosphere<br>$N_B$ | Ocean<br>$N_O$ | Stratosphere<br>$N_S$ | Total<br>$N_T + N_B + N_O + N_S$ |
|---------------|----------------------|--------------------------------|----------------|-----------------------|----------------------------------|
| Minimum       | 3.6                  | 0.2                            | 0.8            | 0.7                   | 5.1                              |
| Most probable | 5.6                  | .2                             | 1.0            | 7.0                   | 13.8                             |
| Maximum       | 3.6                  | .2                             | 1.5            | 22.5                  | 27.8                             |

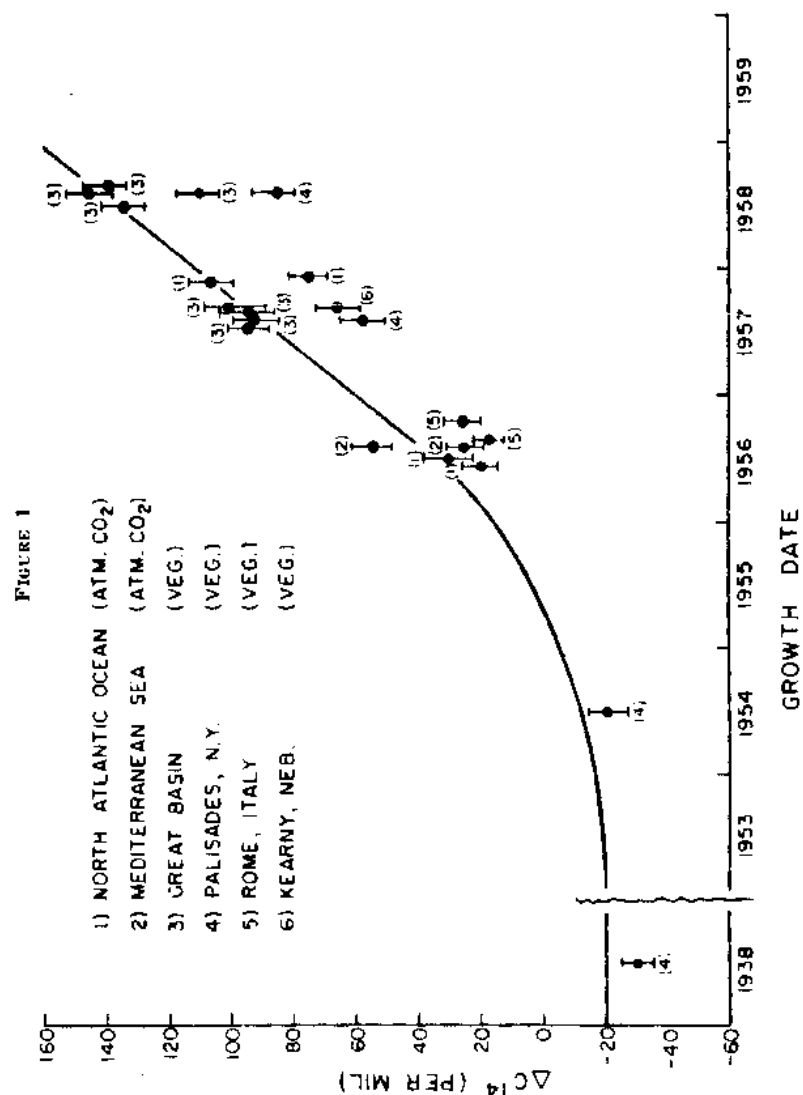
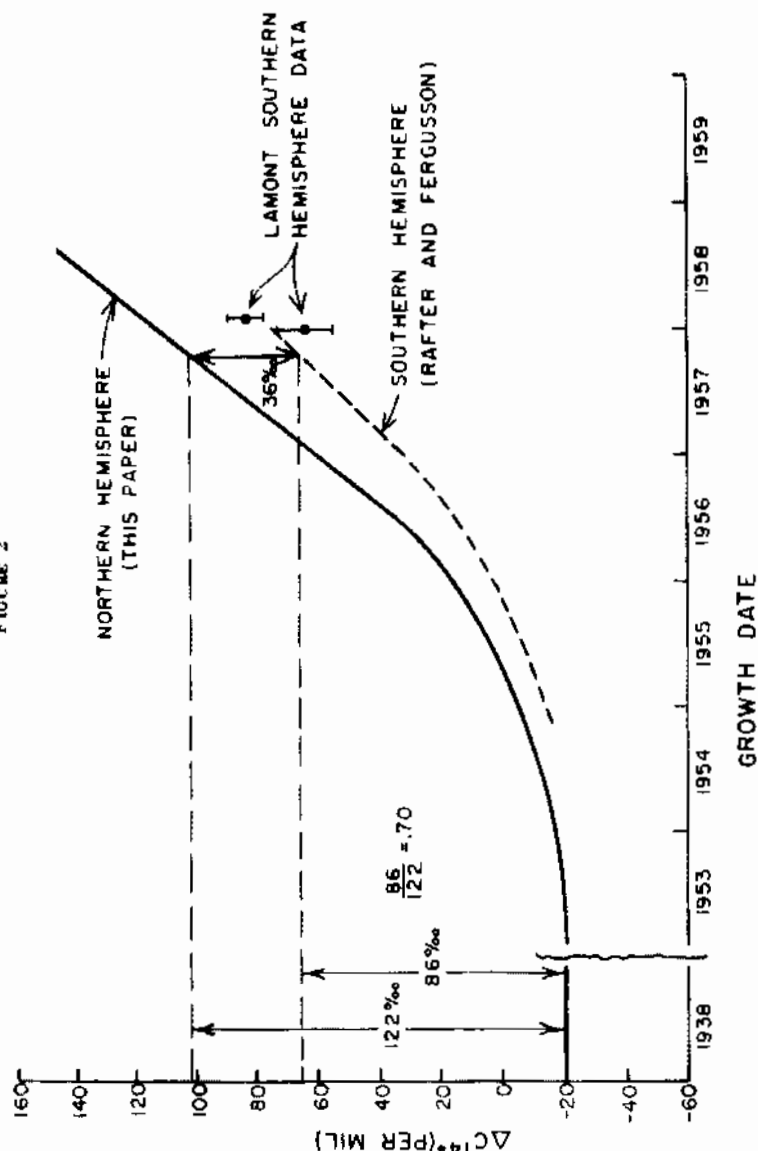


FIGURE 2



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- (12) A more detailed discussion of this scale will appear in the first Radiocarbon Supplement of the *American Journal of Science* (1959).
- (13) As first shown by Suess (*Science*, 122, 415 (1955)) the release of fossil  $CO_2$  as of 1950 had reduced the  $C^{14}$  concentration in the atmosphere by 3.4 percent on the east coast of the United States. More recently Fergusson (*Proc. Roy. Soc. A.*, 243, 561 (1958)) has shown that the average effect over the surface of the earth lies closer to 2 percent. Numerous measurements besides those published by Suess indicate that the effect is larger than 2 percent in industrial areas. (See, for example, Munnich and Vogel<sup>(4)</sup>).
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- (17) The program is a cooperative project carried out under the direction of M. Ewing, R. Gerard, and B. Heezen of the geophysics group and W. Broecker, E. Olson, and J. L. Kulp of the geochemistry group. The results reported in table 2 as well as the air samples reported in table 1 were collected from the Columbia research vessel *Vema* as part of this program. Preliminary results have been reported at the Endicott Nuclear Geophysics Conference (Broecker, W. S., Ewing, M., Gerard, R., Heezen, B. C., and Kulp, J. L. (1958), *National Academy of Science and National Research Council Publication* 572, 118). A comprehensive summary of the results of this investigation will be published soon.
- (18) Financial support for the oceanic sampling and analyses program has been provided by the Atomic Energy Commission (grant AT (30-1)1808) and by the International Geophysical Year organization. The terrestrial samples were measured in connection with a program supported by the National Science Foundation (grant NSF G 4191). The authors appreciate the help and encouragement provided by J. L. Kulp and the extremely valuable review and criticism of the manuscript by E. A. Olson.

STATEMENT CONCERNING THE CONCENTRATION OF BOMB PRODUCED  $C^{14}$  IN THE HUMAN BODY

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The  $C^{14}$  produced by the interaction of the intense neutron flux from nuclear explosions with the  $N^{14}$  atoms of the earth's atmosphere has been recognized as a potential hazard to mankind. Two questions must be answered in order to evaluate the magnitude of this hazard: (1) What is the present level of bomb  $C^{14}$  in the human body and how will it change with time? and (2) What are the adverse effects produced by a given level of  $C^{14}$  in the human body? The present investigation provides information bearing on the first question only.

The fact that most of the  $C^{14}$  produced during nuclear tests is immediately oxidized to  $CO_2$  gas greatly simplifies the problem of prediction of the distribution of bomb  $C^{14}$  in nature. Unlike  $Sr^{90}$  and  $Cs^{137}$  its residence time in the troposphere is measured in years rather than days insuring far more complete geographical mixing. Also, since  $C^{14}$  is itself an isotope of a major element, no large fractionations occur during transfer from one reservoir to another as is the case for  $Sr^{90}$  and its major-element carrier, calcium.

The fate of a bomb  $C^{14}$  atom is most easily understood by considering the various reservoirs for carbon on the surface of the earth. Besides the  $CO_2$  in the atmosphere there are the organic materials which make up the terrestrial biosphere and humus, the dissolved bicarbonate, carbonate, and organic material of the ocean, and the carbon stored in rocks (coal, oil, limestone \* \* \*). Since the rate of addition of new material to the latter reservoir is very slow, most of the bomb  $C^{14}$  produced will remain within the dynamic carbon reservoir (atmosphere, ocean and biosphere) until destroyed by radioactive decay. Since the oceans contain over 90 percent of the carbon in the dynamic reservoir the rate of transfer of material to this reservoir is of major importance. For whereas a small amount of bomb  $C^{14}$  added to the atmosphere can initially appreciably alter the  $C^{14}$  concentration of atmospheric  $CO_2$ , subsequent mixing with the rest of the system will reduce the concentration in atmospheric  $CO_2$  by more than a factor of 10. Hence an understanding of exchange rates of  $CO_2$  between the atmosphere and oceans and mixing rates within the oceans become of major importance in predicting future levels of bomb  $C^{14}$ .

The fact that  $C^{14}$  follows carbon through its cycle allows the level of bomb  $C^{14}$  in humans to be estimated from a knowledge of the bomb  $C^{14}$  concentration in atmospheric  $CO_2$ . Since with the exception of marine fish our diet consists almost entirely of carbon produced by the photosynthesis of atmospheric  $CO_2$ , only the lag time between photosynthesis and incorporation into body tissue must be considered. Direct comparison between the bomb  $C^{14}$  concentration in carbon from human tissue and that in atmospheric  $CO_2$  for a limited number of cases will uniquely establish the magnitude of the lag. If, for example, the lag turns out to be 2 years it will be possible to say that the bomb  $C^{14}$  concentration in human carbon in 1960 will be the same as that measured for the atmosphere in 1958.

With this background in mind results of the laboratory investigations carried out to date can be summarized. Measurements of the  $C^{14}$  concentration in Northern Hemisphere tropospheric  $CO_2$  and in materials extracting  $CO_2$  from this source suggest that the level has been rising at the nearly uniform rate of 5 percent per year. In August 1958 the level was about 16 percent higher than that prior to 1954. Measurements made largely by the New Zealand Radiocarbon Laboratory suggest that the Southern Hemisphere atmosphere has shown an increase about 70 percent as large as that in the Northern Hemisphere. Since most bomb testing has taken place in the Northern Hemisphere, rapid interhemispheric mixing of the atmosphere is suggested.

Since some of the plant materials measured show bomb  $C^{14}$  concentration up to 50 percent lower than that in the average atmospheric  $CO_2$ , it is possible that some food plants will not directly reflect the average atmosphere. This effect may be related to the uptake of soil  $CO_2$  by the growing plants. Since much of the decaying plant material in the soils was formed prior to 1954 such  $CO_2$  will be deficient in bomb  $C^{14}$ . More work is needed before the importance of this effect can be evaluated.

Samples of human materials (breath  $CO_2$ , blood, and tissue) indicate that as expected the lag between photosynthesis and human uptake of carbon is not more than 2 years.

Estimates of the amount of bomb  $C^{14}$  in each reservoir suggest that man had produced from 5 to 20 by  $10^{27}$  atoms of  $C^{14}$  as of March 1958. The main uncertainty in this estimate results from lack of knowledge of the stratospheric inventory. If the stratospheric storage time is 3 years the total inventory is probably about 20 by  $10^{27}$  atoms. The inventory of cosmic ray produced  $C^{14}$  is about 2000 by  $10^{27}$  atoms. Thus complete mixing of the bomb  $C^{14}$  produced up to March 1958 will result in a net increase of 0.5 percent in the level of  $C^{14}$  in humans. The present level (10 percent higher than that of the prebomb era) is a transient one reflecting the finite mixing rates within the dynamic carbon reservoir.

The important question is, How long will it take before complete mixing has occurred? Our lack of knowledge concerning the large scale circulation in the deep oceans makes such estimates quite uncertain. From our present knowl-

edge it seems reasonable however that mixing will occur at a rate resulting in a twofold reduction of the atmospheric concentration every 10 to 70 years.

After complete mixing occurs the residual atmospheric bomb  $C^{14}$  will disappear at the rate of half every 5,600 years.

In summary, fairly reliable estimates of future levels of existing bomb  $C^{14}$  in humans can be made from data on the  $C^{14}$  concentration in atmospheric  $CO_2$  alone providing that the following information can be obtained (order of decreasing importance).

- (1) The patterns and rates of oceanic circulation.
- (2) The source and mean residence time of carbon in terrestrial plants and humus.
- (3) The residence time of  $CO_2$  in the stratosphere.
- (4) The residence time of carbon in human tissue.

[To be submitted to Science]

#### BOMB $C^{14}$ IN HUMANS

**Abstract.**—The concentration of bomb-produced radiocarbon in humans can be expected to lag behind the rising concentration in atmospheric  $CO_2$ . Measurements on human materials suggests a lag of about 1 year for both breath  $CO_2$  and blood, with the suggestion of a somewhat higher value for lung tissue. These results are in reasonable agreement with predictions based on independent evidence.

In evaluating the hazard to man of bomb-produced radiocarbon, one of the factors which must be considered is the relationship between the  $C^{14}$  concentration in the carbon of the human body and that in the carbon of atmospheric  $CO_2$ . Several investigators (1, 2, 3, 4) have published data on the atmospheric radiocarbon increase resulting from nuclear tests. To the author's knowledge no comparable information has been published for the human body.

To date three measurements of contemporary body radiocarbon have been made in this laboratory using the techniques described by Broecker et al. (4). The results given in table 1 are expressed as per mil difference from the  $C^{14}$  concentration of a standard sample (5). In order to eliminate differences resulting from isotopic fractionation,  $C^{13}/C^{12}$  ratios were determined on the counting gas for each sample, allowing the radiocarbon results to be normalized to a common  $C^{13}/C^{12}$  ratio. (See last column, table 1.)

The results are plotted in figure 1 along with the curve published by Broecker and Walton (5) for the  $C^{14}$  concentration in average Northern Hemisphere tropospheric  $CO_2$  as a function of time. Since all the results are normalized to the same  $\delta C^{13}$  value, displacements from the curve reflect only a lag between the human materials and the average atmosphere. For blood and breath  $CO_2$ , this lag is 1.1 years and for lung tissue 1.8 years.

Ideally only two factors should contribute to this timelag: (1) the time between photosynthesis of food and consumption by humans and (2) the residence time of carbon in human tissue. However, if the curve of figure 1 does not represent the atmosphere in which foods eaten by the sample subjects were grown, this fact will also influence the lag times. As discussed below, the ideal lag times are probably less than the values obtained from figure 1.

As pointed out by Suess (6) and by Fergusson (7), plants growing in industrial areas show a greater fossil  $CO_2$  effect (i.e., lower  $C^{14}$  concentration) than those growing in areas removed from industrial activity. In addition, Munnich and Vogel (3) have suggested that plants growing in zones of dense vegetation may incorporate  $CO_2$  given off by decaying organic materials in soils. Since the curve of Broecker and Walton is based on samples collected in areas remote from both industrial activity and dense vegetation, part of the observed lag times as obtained in figure 1 may be due to local depression of the  $C^{14}$  concentration in atmospheric  $CO_2$ .

Although it is not possible to predict how great this effect might be, a few assumptions can give an idea as to magnitude. If the local "Suess effect" (i.e., dilution with industrial  $CO_2$ ) were to be 1 percent greater than the world-average value of 2 percent (7), the lag time as measured in figure 1 would be 0.2 years too long; this is based on the presently observed atmospheric increase of 5 percent per year. Furthermore, if plants were to photosynthesize a significant amount (say 10 percent) of decay  $CO_2$  and if this  $CO_2$  were derived mainly from organic

material grown before bomb testing began, then an apparent lag of 4 months would be introduced. Thus, it is evident that lagtimes read from figure 1 are maximum values.

A crude estimate of the lag between photosynthesis and human consumption can be made by considering the average American diet. For fruits, vegetables, and grains, the time is not likely to exceed 1 year, for the supply of these foods is completely replenished each growth season. Milk products should have a similar timelag, since the milk should closely reflect the animal diet (a cow produces its own body weight of milk in 3 months). An analogous situation exists for eggs. On the other hand, meat may show a longer lag, since the mean residence time of carbon in the animal must be taken into account. Since meat provides less than 20 percent of the carbon in the average diet, this effect is probably not sufficient to raise the average lag to more than 1 year.

To the authors' knowledge the biological half life for carbon in the soft tissue and bone of man has not as yet been determined. For soft tissue in rats the value is 35 days (8), but as shown by Richmond and Langham (9), who have determined biological half times of alkali metals in various mammals, the residence time for humans may be considerably different than for rats (for  $\text{Cs}^{137}$  it is a factor of 6.5 longer). A lower limit for the turnover time can be obtained by dividing the carbon content of the body by the amount of carbon metabolized per day. The latter may be computed as food intake less fecal excretion or as respiratory  $\text{CO}_2$  plus urinary carbon. In either case, the result is about 300 grams of carbon. For a 150-pound person, therefore, the minimum turnover time for the body as a whole is about 40 days. This figure is also the length of time which respiratory  $\text{CO}_2$  should lag behind ingested food.

From the foregoing information, these three conclusions are warranted:

- (1) The interval between the fixation of carbon in average food and the consumption of that food is less than 1 year (i.e., less than 1.1 years minus 40 days).
- (2) The maximum time which blood lags behind food is about 6 months; in other words, the mean residence time of a carbon atom in the blood is no more than 6 months. This is based on an upper limit ( $2\sigma$ ) for the difference between blood and respiratory  $\text{CO}_2$  (20 per ml) converted to months through division by 4 per ml per month (equivalent to the slope of the atmospheric curve in fig. 1) and supplemented by the 40-day lag between breath and food.
- (3) The carbon of lung tissue has a somewhat longer mean residence time than that of blood.

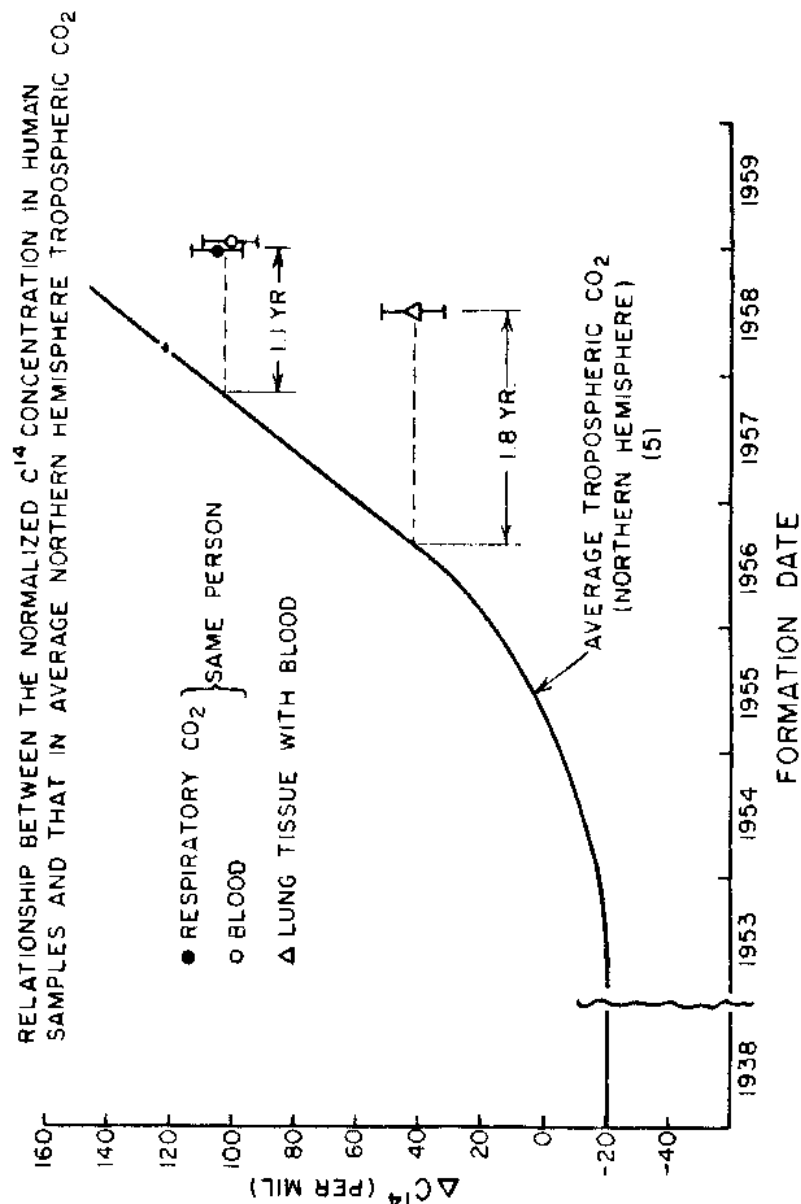
From this discussion it is evident that more measurements are needed. Among other things, further measurements should answer these three major questions: (1) To what extent does decay  $\text{CO}_2$  enter growing plants? (2) To what extent can variation in diet affect the lagtime? (3) What is the mean residence time of carbon in human soft tissue and in human bone? Answers to these questions will provide further data needed in assessing the hazard to man of bomb-produced radiocarbon (10).

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TABLE 1.— $\text{C}^{14}/\text{C}^{12}$  ratios for human materials

| Sample No. | Sampling date | Sample description                                                 | $\delta\text{C}^{14}$ | $\delta\text{C}^{13}$ | $\Delta\text{C}^{14}$ |
|------------|---------------|--------------------------------------------------------------------|-----------------------|-----------------------|-----------------------|
| L-371A     | June 1958     | Lung tissue (with associated blood) from a New York City resident. | $61 \pm 10$           | -14.7                 | $42 \pm 10$           |
| L-306A     | Jan. 1, 1959  | Respiratory $\text{CO}_2$ from a resident of Rockland County, N.Y. | $106 \pm 8$           | -21.8                 | $105 \pm 8$           |
| L-303B     | Jan. 1, 1958  | Blood from same person as L-305A.                                  | $115 \pm 8$           | -16.3                 | $102 \pm 8$           |



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- (10) This work is sponsored by the Atomic Energy Commission (contract AF (30-1) 1455). The authors acknowledge the technical assistance of James Hubbard, Marilyn Zickl, and Ross Horowitz. Dr. J. L. Kulp has provided help and encouragement for which the authors are appreciative. Lamont Contribution No.

STATEMENT OF DR. HARRY WEXLER, DIRECTOR OF METEOROLOGICAL RESEARCH, U.S. WEATHER BUREAU, TO THE JOINT COMMITTEE ON ATOMIC ENERGY HEARINGS ON FALLOUT, MAY 5-8, 1959

The statement which I submitted during the 1957 fallout hearings included recommendations to improve our understanding of the mechanics of storage, transport, and removal of radioactive materials in the atmosphere. These recommendations, in my opinion, are still valid and I am happy to report that some of them have been partially implemented:

## 1. METEOROLOGICAL OBSERVATIONS IN THE STRATOSPHERE

As a result of emphasis given during the International Geophysical Year on high altitude exploration of the atmosphere, the average height of the U.S. network of radiosonde balloons has increased from 60,000 to 75,000 feet. In addition, there has been a lateral expansion of the networks from the North Pole to the South Pole. Much has been learned of similarities and contrasts in behavior of the stratospheres in the Northern and Southern Hemispheres, particularly in the polar regions.

Some progress has been made on the development of a relatively inexpensive lightweight rocket capable of carrying meteorological instruments to at least 200,000 feet to measure wind and temperature in the important 100,000 to 200,000-foot layer located above the usual balloon ceiling. It is hoped that after the period of testing now going on has been completed, means can be found to establish widespread synoptic networks over large portions of the earth's surface. The U.S.-IGY rocket flights at Churchill, Canada, using heavier, more expensive rockets, capable of going to greater heights, have revealed a great deal of unsuspected information on the structure and motions of the subarctic stratosphere.

## 2. AIR SAMPLING AND ASSAYING IN THE STRATOSPHERE

While progress has been made in obtaining air samples and measurements in the stratosphere for a determination of radioactivity, the available AEC observations are still too scattered in time and space and apparently of not sufficient quality to answer the host of pressing meteorological questions relating to the stratospheric storage, diffusion, and exchange with the lower atmosphere. With regard to the latter, during the past few years natural cosmic-ray-produced radionuclides have revealed the presence of stratospheric air in the troposphere. Better understanding of stratospheric circulation and transport will result from the tracking of radioactive tracers, both natural and artificial. However, to exploit the use of these tracers, we must greatly expand our field program involving specially equipped aircraft, balloons, and rockets to obtain stratospheric air samples and measurements. Since there

are so many conflicting theories in this field, it is important that such expanded observational program be under the technical direction of a meteorologist who has specialized in this field.

## 3. PREDICTION OF STRATOSPHERIC TRANSPORT AND MIXING

The high-speed automatic electronic computer and its associated data processing equipment are being used more and more successfully in handling the weather analysis and prediction problem in the lower atmosphere. Development of similar computational models for the stratosphere has been slow primarily because of lack of observations in the stratosphere. Here again the IGY has contributed significantly by stimulating collections of data by radiosondes, rockets, and satellites.

From the expanded radiosonde network in both polar stratospheres it is becoming more apparent that the dynamics of the stratospheric circumpolar vortex play an important role in large-scale mixing processes in the stratosphere. The dramatic mid- or late-winter breakdown of the Arctic stratospheric vortex which does not seem to have a counterpart in the Antarctic, introduces vigorous horizontal and up-and-down motions which undoubtedly play a major role in mixing and moving large quantities of stratospheric air through the tropopause gap into the lower atmosphere at middle latitudes. This breakdown appears to be associated with the formation of islands of hot and cold air in the stratosphere, some of which according to the rocket measurements at Churchill, extend up to more than 150,000 feet thus indicating that these motions affect a deep layer of the stratosphere. The reasons for this sudden breakdown of the stratospheric vortex in the Arctic but not in the Antarctic are not quite clear. It is possible that this may stem from the difference in the geography of the two hemispheres. It is also possible that solar and cosmic energy trapped in the Van Allen radioactive belt, discovered by recent satellites, may be bled off sporadically in the auroral zones and initiate thermal and kinetic response of the underlying atmosphere. But why this should affect one polar region and not the other is not clear.

All these new data and concepts make it more pressing that mathematical models for stratospheric circulations be set up and solved on electronic computers.

Although a start has been made in implementing the recommendation made in 1957 in this area, much more needs to be done to exploit the new sources of data and to apply modern computer and data processing techniques.

## 4. REMOVAL PROCESS

A program to study the removal processes of atmospheric dust particles has been initiated. At Mount Washington, N.H., natural clouds have been sampled for strontium 90. The results strongly suggest that the radioactive particles enter the rain or snow while the latter are present as small cloud droplets. Laboratory studies at the Armour Research Foundation in Chicago are designed to understand the mechanism by which this collection occurs. Another field experiment at the Massachusetts Institute of Technology in Cambridge will try to relate the scavenging of radioactivity to the nature of the precipitation. It appears likely that further research can uncover the means by which rain removes atmospheric aerosols.

But there is another aspect of the removal process which we are unable to study. This is the impact of particles on quasi-vertical surfaces like trees, buildings, and so forth. The removal of this mechanism is not included in the budgeting of fallout as computed from soils or rainfall collecting pots. If we could assure ourselves that the fraction of radioactivity removed by this mechanism is negligible it would be unnecessary to expend any major effort to understand the details of the process.

While not entirely a meteorological problem, an intensified effort should be directed to the problem of soil versus deposition on herbage as the source of strontium 90 in food. Admittedly, a difficult project, its importance in predicting future levels of strontium 90 in people is so important that a more vigorous effort to solve it is justified.

## METEOROLOGICAL ADVANTAGES RESULTING FROM THE ATOMIC TEST MORATORIUM

In the past the work of studying stratospheric versus tropospheric storage, transport, mixing, and fallout has been greatly complicated by the large number of injections of radioactive material into the atmosphere. Now that no new injections have been made in the past 6 months it becomes easier to eliminate certain troublesome problems. For example, since the tropospheric fallout is much faster than the stratospheric fallout, because of the efficient scavenging of precipitation, as time goes on any of the material originally injected in the troposphere will vanish and the debris stored in the stratosphere will contribute practically all of the fallout. It is important that the data collection and analysis program not only be continued but be intensified along the lines given above for several years, especially if no new injections of radioactive materials are made into the atmosphere. This opportunity to utilize these artificial radioactive tracers may never again present itself if future injections are made as they were prior to November 1958, and we may never find the answers to some of these important meteorological questions relating to the intensity and geographical area of fallout.

## POSSIBILITY OF LOSS TO SPACE

It is known from the Argus experiments that much of the radioactive debris released from nuclear explosions at about 300 miles stayed outside the earth's atmosphere and spread over the earth as part of the inner zone of the Van Allen radioactive belt. It is conceivable that nuclear explosives occurring at lower elevations might also lose a part of their radioactive debris to space instead of being deposited on the earth. It is important that careful study be given to the possibility that there exists some height in the atmosphere, above which all, or nearly all, of the radioactivity released by a nuclear explosion may not return to earth.

UNIVERSITY OF CALIFORNIA MEDICAL CENTER, DEPARTMENT AND LABORATORIES,  
NUCLEAR MEDICINE AND RADIATION BIOLOGY

## SUMMARY STATEMENT OF FINDINGS RELATED TO THE TESTING PROGRAM AT NEVADA TEST SITE

(By Kenneth H. Larson, Chief, Environmental Radiation Division; James W. Neel, Chief, Biophysical Relationships Section, and associates)

During the last decade the Environmental Radiation Division has been involved in progressively intensified programs designed to answer one principal question, viz, how much man-made radioactivity distributed in the environment can be tolerated safely by man and his economy?

The more specific objectives of our effort within this broad context include:

1. Delineation of fallout patterns and their characteristics with respect to particle size through which the mechanics of fallout can be more accurately defined. This, in turn, leads to a comparison of the effects of the yield of device detonated, type of device support, and the relation of the detonated device to ground surface upon the resultant fallout radiation intensity including the residual radioactivity per unit surface area within the fallout pattern.

2. A detailed study of the chemical, physical, and radiological characteristics of fallout debris relative to its particle size and occurrence within the fallout pattern.

3. Determination of the biological availability, rate of accumulation, and retention of the fallout debris in various native and domestic plants and animals, as well as the persistence and redistribution of residual contamination in the total environment.

Environmental studies have clearly revealed that (1) biological effect (or hazard) cannot be realistically assessed on the basis of measurement of only the gamma radiation field. Fission products from radioactive debris produced by man are being assimilated by animals with the maximum degree of accumulation not necessarily near the source of the nuclear reaction. Further, within a distance of 400 miles from the Nevada test site, the plant foliage is a selective particle collector. There has been no significant accumulation of activity through the root system. (2) Biological availability of fallout debris is strongly influenced by the conditions of contamination and by the physical and chemical nature of the contaminating material and its interaction with environmental

factors. (3) Within 200 miles from the Nevada test site  $\text{Sr}^{90}$  and  $\text{Sr}^{90}$  are estimated to be less than 10 percent of the total theoretical  $\text{Sr}^{90}$  and  $\text{Sr}^{90}$  generated by all detonations at the Nevada test site since the Ranger test series.

## Fallout phenomenology and its characteristics

Fallout from test devices detonated at Nevada test site is governed by many complex variables such as: energy yield; wind structure; the support used for the detonation of devices; ground surface; degree of fireball intersect with ground surface; and mass of inert material surrounding the device. The data presenting the resultant effects and characteristics of fallout from the various detonations studied by this laboratory are summarized in the following statements:

1. *Improvements in early measurement of fallout.*—The coordination of aerial survey measurements of fallout patterns with ground measurements using fallout radiation-calibrated survey instruments has greatly increased the detail and accuracy of fallout pattern delineation and the distances to which fallout patterns can be detected.

By use of aerial survey equipment techniques of the U.S. Geological Survey, fallout radiation intensities within approximately 10,000 square miles can be measured in about 12 hours. Aerial measurements agreed within  $\pm 10$  percent of measurements taken 3 feet above the ground by survey meters. Fallout patterns were routinely measured to distances of 300 miles from ground zero or less; however, one tower shot pattern was extended as far as 700 miles from the Nevada test site, and levels were still readily detectable at the termination point. Fallout intensities as low as 0.1 mr/hr were subject to errors of less than  $\pm 20$  percent due to natural background radioactivity fluctuations.

The response of eight different types or models of hand-carried survey instruments to fallout radiation was as much as  $\pm 35$  percent of that observed for a reference type of instrument (Radac Model AN/PDR-T1B). Comparative measurements in fallout radiation fields yielded factors which normalized readings to fission product mixtures.

2. *"Local" fallout levels of radiation.*—Proximity to ground surface as well as increased mass of support and cab structures increased fallout in areas adjacent to the Nevada test site.

Aerial bursts were not detectable by ground survey methods within 200 miles of ground zero. Two 1,500-foot balloon shots which did not intersect the soil surface deposited less than 0.2 percent of the theoretical fallout activity<sup>1</sup> within the 1 mr/hr radiation intensity contour (at H+12 hours) between the distance of 1 mile from ground zero and that corresponding to a fallout time of H+12 hours. A balloon shot which intersected the soil surface deposited 2.12 percent of the theoretical fallout. Tower shots, which in some cases intersected the soil surface and in other cases did not, deposited 6.7 to 24.5 percent of the theoretical fallout activity within the same distance limits.

3. *Particle size distributions in fallout patterns.*—Fallout particle sizes decrease with distance from ground zero and with lateral distance from the midline of fallout. The relative amount of radioactivity associated with small particle sizes (less than 44 micron) and hence the amount of fallout occurring at greater distances from ground zero was increased by decreasing the mass of support and cab materials.

We found that vegetation in the environs of Nevada test site during the teapot series retained only the 0-44 micron fallout particle fraction. Therefore, this size range has been emphasized in our recent studies.

Within the limits of 1 mile from ground zero to a distance corresponding to H+12 hour fallout time, 500- and 700-foot tower shots had approximately 30 percent of the fallout activity associated with particles less than 44 microns in diameter. A 700-foot balloon shot had 70 percent of the fallout activity associated with the same size fraction.

On the average, 38 to 50 percent of the less than 44 micron-diameter fallout activity of tower shot fallout samples was associated with the less than 5 micron-diameter particles and 51 to 83 percent in the case of balloon shot samples. Various percentage contributions of less than 5 micron-diameter fallout particles were observed at virtually all sampling locations for both tower and balloon shots.

<sup>1</sup> The theoretical potential fallout is calculated on the basis of 300 gamma megacuries at H+1 hour per KT yield.



4. *Solubility of fallout materials.*—Solubility is one of the most important properties of fallout with respect to the internal emitter problem in biological systems. As indices of biological availability, we arbitrarily use the solubility of fallout material in water and 0.1 N HCl.

The solubilities of balloon shot fallout materials exceeded those of tower shot materials in both water and acid. The solubility of tower shot fallout increased with decreasing particle size. However, in the case of balloon shot fallout, the smaller particles were somewhat less soluble than larger particles.

(In percent)

|                                                                   | Fallout material from— |               |
|-------------------------------------------------------------------|------------------------|---------------|
|                                                                   | Tower shots            | Balloon shots |
| Water solubility expressed as percent total beta activity:        |                        |               |
| Greater than 44 micron fraction                                   | <1                     | 31            |
| Less than 44 micron fraction                                      | <2                     | 14            |
| 0.1 N HCl solubility expressed as percent of total beta activity: |                        |               |
| Greater than 44 micron fraction                                   | 5                      | >90           |
| Less than 44 micron fraction                                      | 14-36                  | >60           |

It should be noted that the beta activity of fallout from the underground shot, Jangle Series, had a solubility greater than tower shots but less than balloon shots for the particle range of less than 44 microns. It was 5.4 percent soluble in water and 25 percent soluble in 0.1 N HCl.

5. *Radiochemical properties of fallout materials.*—Small particle sizes had higher percentages of radiostrontium and radoruthenium at 30 days after shot than larger particle sizes. The percentages of radiostrontium and radoruthenium in balloon-shot fallout were several times higher, and radiozirconium lower, than in corresponding particle sizes of tower-shot fallout. Percentages of radio-barium, radiocesium, and radioyttrium varied to a lesser degree between tower- and balloon-shot fallout. Strontium 90 averaged 2.7 percent of total radiostrontium in tower-shot fallout at D+30 days.

The distribution, as of D+30 days, of radioisotopes of Ba, Ce, Ru, Sr, Y, and Zr with respect to different particle sizes of tower- and balloon-shot fallout is illustrated in figure 1. The average radioactivity values expressed as percent of the total activity due to the primary contributing isotope(s) as D+30 days are summarized below:

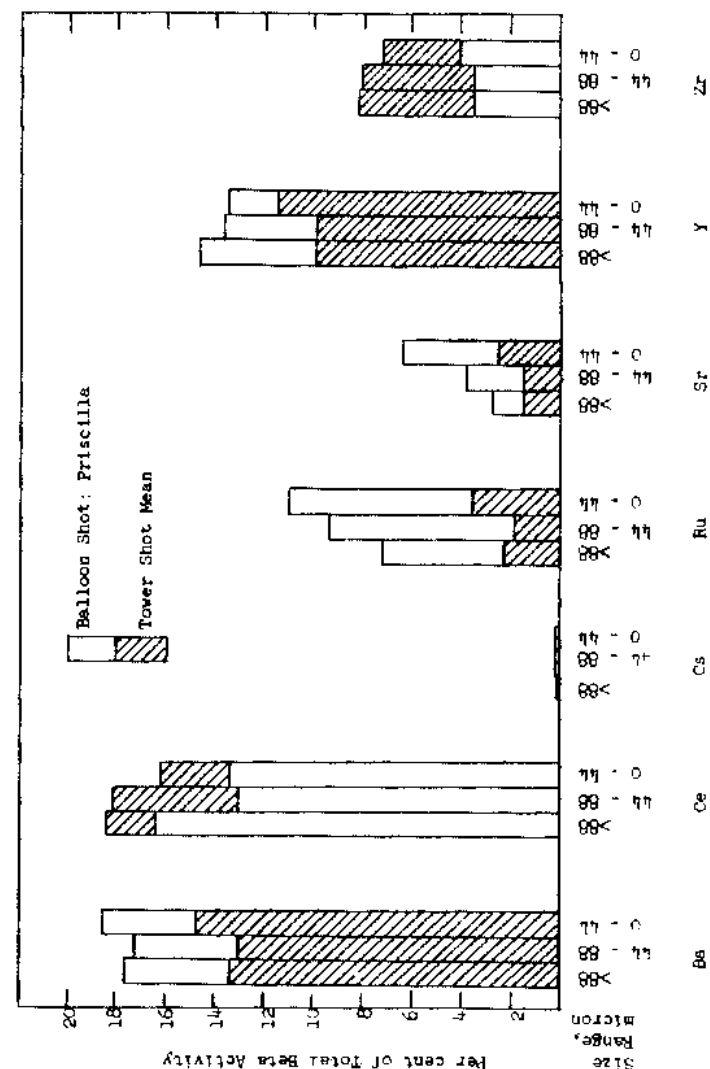
Average percent of activity at D+30 days

| Isotope           | Tower | Balloon | Theoretical $U^{235}$ fission products <sup>1</sup> |
|-------------------|-------|---------|-----------------------------------------------------|
| Ba <sup>140</sup> | 13.7  | 17.9    | 10.40                                               |
| Ce <sup>144</sup> | 17.6  | 14.3    | 13.10                                               |
| Ru <sup>106</sup> | 2.6   | 9.2     | 5.99                                                |
| Sr <sup>90</sup>  | 1.83  | 4.3     | 6                                                   |
| Y <sup>91</sup>   | .05   | —       | .08                                                 |
| Zr <sup>95</sup>  | 10.4  | 14      | 7.74                                                |
| Zr <sup>95</sup>  | 7.8   | 3.83    | 8.13                                                |

<sup>1</sup> Rolles and Ralieu, USNRDL-456.

FIGURE 1

Comparison of Radioelement Percentages of Different Particle Size Fractions of Tower and Balloon Shot Fallout



6. *Deposition of biologically available radioisotopes.*—A comparison of a balloon and a tower shot having similar KT yield and the same detonation height indicated that over a 1- to 15-hour fallout time period the amounts of water-soluble radio-barium and radiostrontium deposited by the 0-44 micron fraction of each shot were similar despite relatively large differences in the 0-44 micron fallout activity level.

The widespread distribution of 0-44 micron fallout from all types of devices detonated at the Nevada test site indicates that this size fraction is the most significant with respect to total area of contamination. Assuming that the soluble fractions of fallout reflect the same radioelement percentages as the original fallout, the application of solubility percentages to radioelement percentages yields the percentages of the various radioelements in 0.1 N HCl and water-

soluble extracts. Based on such calculations, the relative amounts of the several radioelements in the soluble fractions of equal amounts of 0-44 micron fallout from a tower and a balloon shot of similar yield and height of detonation appear in figure 2. The deposition of 0-44 micron fallout from the tower shot, however, considerably exceeded that of the balloon shot at different fallout times from 1 to 15 hours (fig. 3). The application of soluble radioelement percentages to measured and integrated 0-44 micron radioactivities of the two shots yields the relative amounts of the various radioelements at different fallout times. As examples, the relative amounts of total acid-soluble and water-soluble radiobarium and radiostrontium derived from the 0-44 micron size fraction deposited by the two shots at various fallout times appear in figures 4 and 5. While the amounts of total and acid-soluble radiobarium and radiostrontium deposited by 0-44 micron fallout from the tower shot are higher over the 1- to 15-hour fallout period, the amounts of water-soluble radiobarium and radiostrontium are similar.

FIGURE 2

Calculated Priscilla/Smoky D + 30 Day Radioelement Ratios in Untreated, Acid-soluble, and Water-soluble Fractions of 0 - 44 micron Fallout

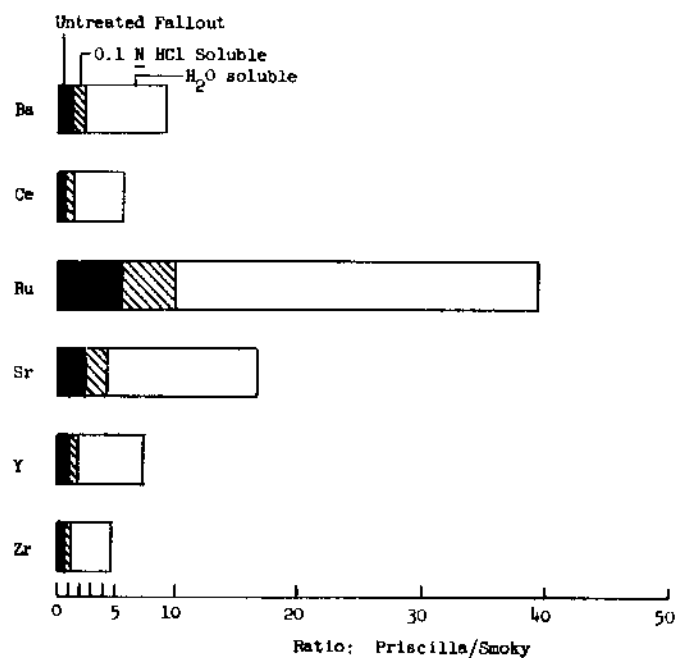


FIGURE 3

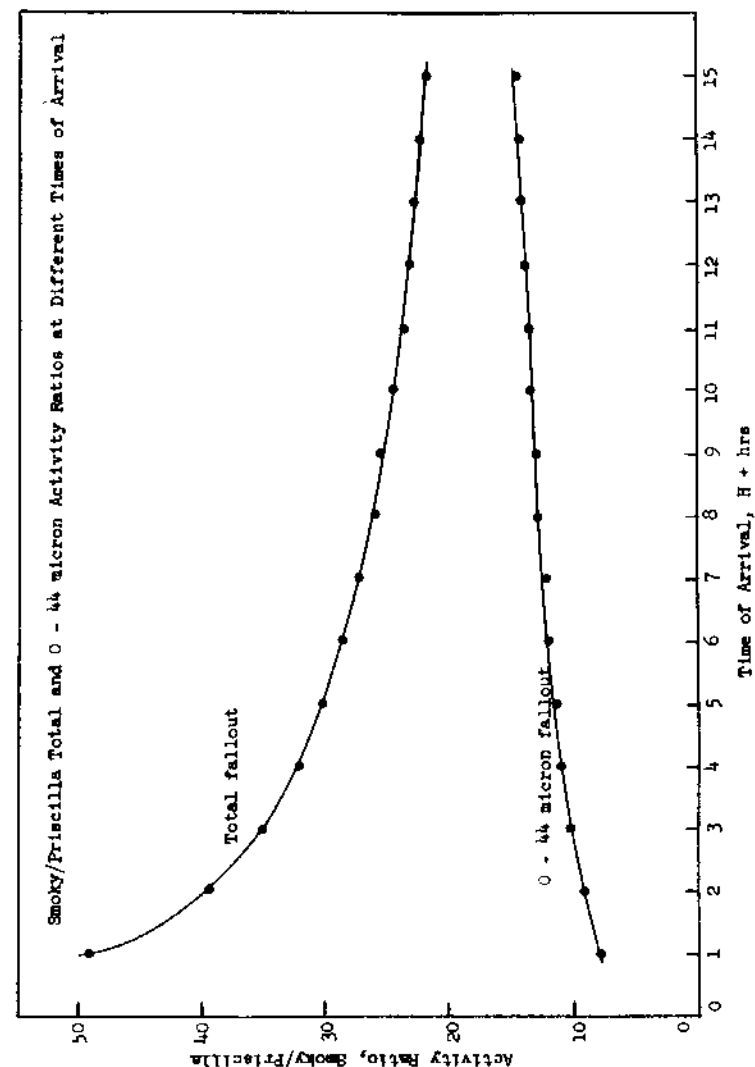


FIGURE 4

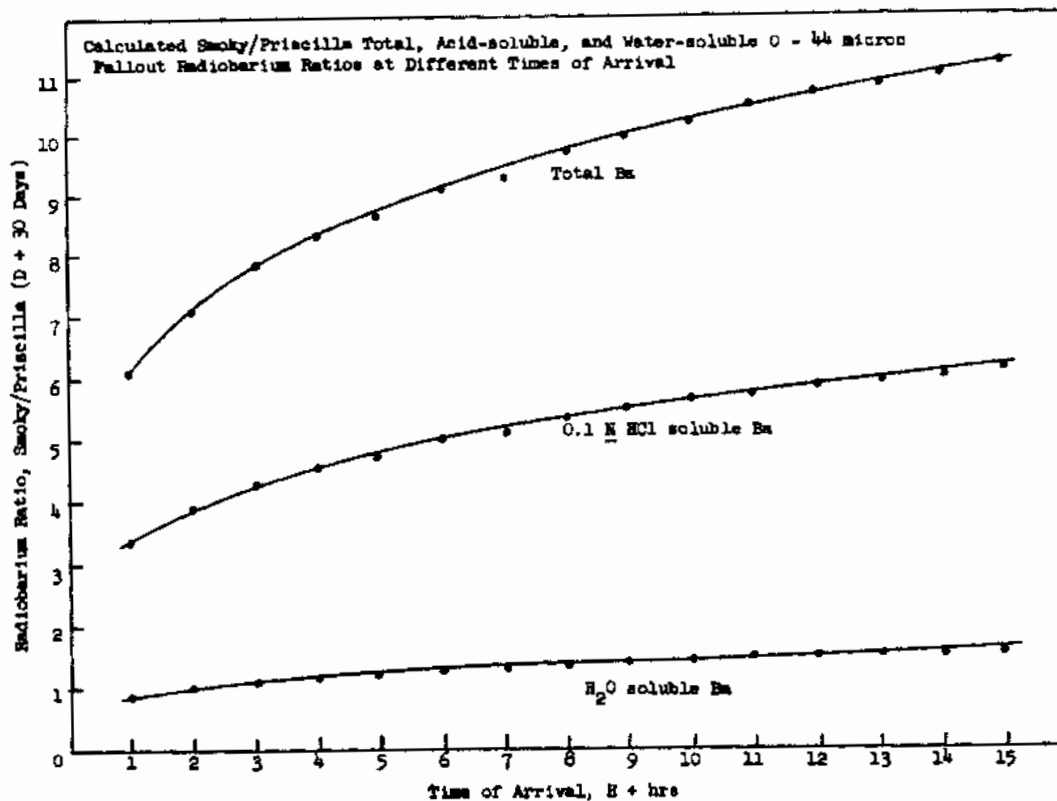
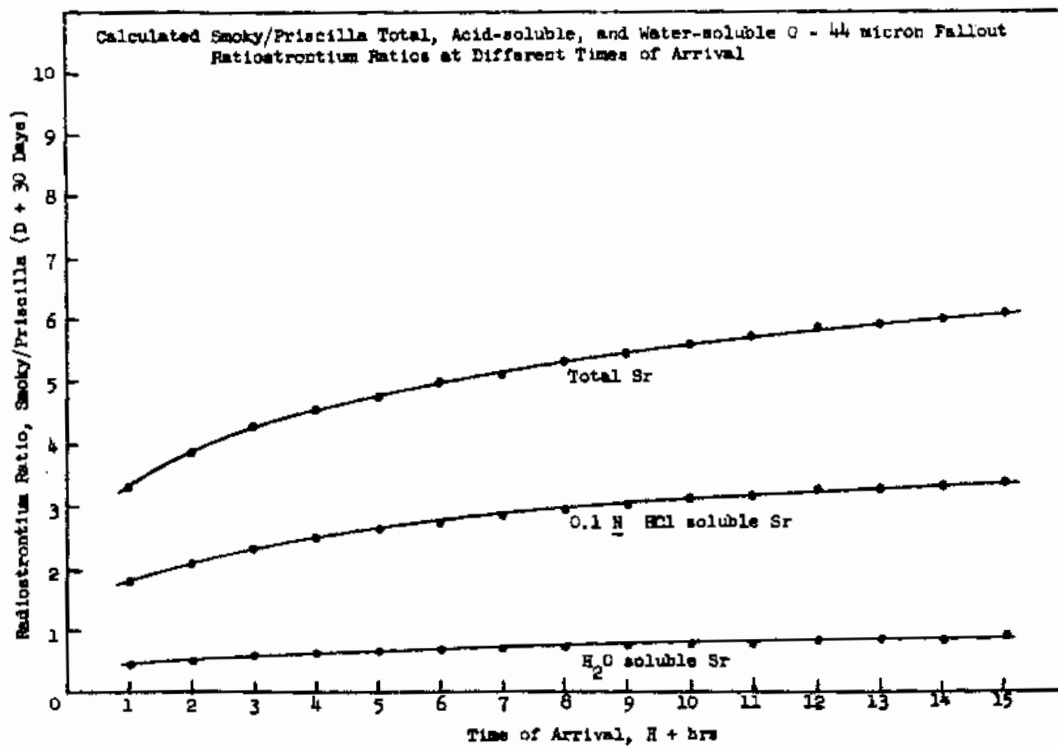


FIGURE 5



7. *Decay of fallout radioactivity.* Fallout materials from a specific shot had similar beta decay curves regardless of particle size and time of fallout. Beta decay curves of most shots approximate the  $T^{-1.2}$  decay relationship from H+12 to H+8,000 hours. Slopes of the order of  $T^{-1.2}$  occurred from H+6,000 to H+10,000 hours.

Decay curves of the gamma emission rate were different from those of beta decay for fallout materials from a specific shot. Gamma decay curves of fallout from different shots were generally similar, but more variable than corresponding beta decay curves. Plumbbob beta and gamma decay curves are illustrated in figure 6 in relation to the  $T^{-1.2}$  decay curve and a theoretical mixed fission product ( $U^{235}$ ) decay curve.

Estimates of dosage in fallout areas have generally been based, in part, on a decline of dose rate (mr/hour) with time according to the  $T^{-1.2}$  relationship. A dose rate decline with time according to the Plumbbob gamma decay curve illustrated in figure 6 yields calculated doses which are 1.5 to 2 times greater than those calculated by the  $T^{-1.2}$  relationship for different fallout times to approximately 400 days after shot (see below):

*Comparison of dose to 10,000 hours calculated on the basis of Plumbbob gamma decay curve and  $T^{-1.2}$  relationship (100 mr/hour at time of arrival)*

| Time of arrival | Plumbbob dose to 10,000 hours | $T^{-1.2}$ dose to 10,000 hours | Plumbbob dose/ $T^{-1.2}$ dose |
|-----------------|-------------------------------|---------------------------------|--------------------------------|
| H+2 hours       | 1,635 mr                      | 818 mr                          | 2.00                           |
| H+4             | 2,633                         | 1,582                           | 1.67                           |
| H+6             | 3,993                         | 2,319                           | 1.72                           |
| H+8             | 4,979                         | 3,041                           | 1.64                           |
| H+10            | 5,917                         | 3,744                           | 1.58                           |
| H+12            | 6,679                         | 4,437                           | 1.51                           |

8. *Deposition of radiostrontium in areas adjacent to Nevada test site.*—A balloon shot, whose fireball intersected the soil surface, deposited 0.13 percent of the total amount of  $Sr^{90}$  produced<sup>2</sup> within a distance of 1 mile from Ground Zero and the distance corresponding to H plus 12 hours fallout time. Two balloon shots, whose fireballs did not intersect the soil surface, deposited 0.004 and 0.008 percent of the total amount of  $Sr^{90}$  produced. Tower shots deposited from 0.5 to 2 percent of the  $Sr^{90}$  produced and from 1.6 to 0.3 percent of the total amount of  $Sr^{90}$  produced.<sup>2</sup>

Calculations were based on the results of  $Sr^{90}$  and  $Sr^{90}$  analyses of fallout samples and integrated fallout radiation intensities converted to curies by ratios of  $\mu\text{Ci}/\text{ft}^2$  and  $\text{mr}/\text{hr}$ . The analysis of balloon shot samples for  $Sr^{90}$  was not performed.

The tower shot percentage deposition of  $Sr^{90}$  is less than that of  $Sr^{90}$  to distances corresponding to H plus 12 hours fallout time. This is due to relatively low percentages of  $Sr^{90}$  in larger particle sizes which generally represent the majority of the fallout activity in areas close to Ground Zero. This fractionation of  $Sr^{90}$  and  $Sr^{90}$  with respect to particle size can be predicted on the basis of the different half lives of their noble gas precursors,  $Kr^{85}$  and  $Kr^{88}$ , respectively.

The percentage deposition of  $Sr^{90}$  is generally lower in the 1 mile to H plus 12 hours fallout time area than that of total fallout (see 2) as a result of low  $Sr^{90}$  percentages in the larger fallout particles.

*Biological availability as related to the fate and persistence of fallout as measured at various locations within fallout patterns up to 400 miles from Nevada test site*

In undisturbed areas the radioactive debris from fallout is confined to the surface 2 inches of the soil profile even after 9 years following fallout contamination (Trinity areas, New Mexico). In agricultural areas under cultivation, the distribution of activity is found down to depths of 4 to 8 inches due to plowing, harrowing, etc. Soil leaching laboratory experiments using the equivalent of 84 inches of water translocated the surface activity only about 0.5 inch into the soil column.

<sup>2</sup> The theoretical potential  $Sr^{90}$  and  $Sr^{90}$  fallout is based on the production of 1 gram or 27,700 curies of  $Sr^{90}$  and 1.14 gram or 146 curies of  $Sr^{90}$  per KT yield at H plus 1 hour.

Surface-deposited fallout tends to become mechanically trapped in the environment. The amount that is redistributed declines with time. Strong disturbance, however, causes material to be redistributed at levels approximating the initial contamination of medium- and long-lived fission products.

Particles 44 to 88 microns in diameter contributed an average of 0.7 percent of the total redistributed fallout following Priscilla (balloon) as compared to 21.0 percent following Smoky (tower) of the Plumbbob test series. Particles less than 44 microns in diameter contributed an average of 85.8 percent following Priscilla compared to 68.3 percent following Smoky.

During the Plumbbob test series, it was found that the gamma radioactive decay measured in the field was similar to the decay of comparable fallout samples measured in the laboratory. Also, the aerosol concentrations were similar following both Priscilla and Smoky despite significant differences in initial contamination.

Forage plants are recontaminated due to redistribution of selected particulates. This provides a continuous source of internal emitters to grazing animals, and a persistent low radiation field which is dependent on the changing proportions of medium- to long-lived fission products. During the Teapot and Plumbbob test series, it was found that the principal source of activity found on forage plants is due to particulate fallout in the less than 44-micron size fraction; i.e., vegetation within fallout patterns out to 300 miles from Nevada test site is a "selective" particulate collector. The number of particles retained by the foliage is dependent upon its characteristics such as hairs, glands, and other mechanical traps. Up to 21.6 percent of the contamination on washed leaves was soluble in 0.1 N HCl, which suggests that a similar percentage of the fallout material ingested would be available to animals.

The fallout contamination of native plant material persisted through the 18-day period following both Priscilla and Smoky, the only change being that due to radioactive decay.

The accumulation of fission products from fallout debris from tower detonations by native forage crops and alfalfa, through the root system, is a negligible fraction of the total contamination on or in the soil (within 300 miles of Nevada test site).

During the 1955 test series, radiolodine,  $I^{131}$ , in the thyroids of rabbits and other native rodents was found to be a function of distance. The maximum concentrations were found at approximately 80 miles. This maximum concentration was a factor of 2 to 7 times higher than that documented at 20 miles or at 160 miles. Twelve months after Upshot-Knothole series, and 6 months after the Teapot series, radiostrontium was also found to be a function of distance, with the maximum bone concentrations in rabbits at 130 miles along previously documented fallout patterns.

Between 82 and 87 percent of the total radioactivity found in the thyroid tissue of the native rodents at H+72 hours consisted of 17 to 20 percent as iodine 131 and 65 to 67 percent as iodine 133. The maximum accumulation occurred at approximately D+14 days with samples taken at D+20 days containing only iodine 131. Of the several fission products ( $Sr^{90}$ ,  $Y^{91}$ ,  $Ce^{144}$ ,  $Cs^{137}$ , and  $Ba^{140}$ ) accumulated in bone, 12.5 to 40.0 percent was accounted for in terms of radiobarium and radiostrontium by D+20 days.

Maximum tissue accumulation of biologically available fission products occurs at locations corresponding to fallout times of H+2 to H+3 hours. Fission product concentrations then decreased with increasing time of fallout. In the single balloon shot studied, the slope of decrease was constant between locations corresponding to H+2 to H+12 hours. In tower shots, however, biologically available fission product concentration tended to be uniform over distances corresponding to H+5 to H+14 hours.

For any given location the relative tissue accumulation of biologically available fission products resulting from Priscilla and Smoky fallout contamination was similar with the peak values occurring by D+7 days.

Biological "hot spots" were identified geographically in the Boltzmann (78 miles from Ground Zero), Diablo (60 miles from Ground Zero), Smoky (70 miles from Ground Zero), and Shasta (172 miles from Ground Zero) patterns.

In the laboratory, the rate of radioactive decay of isolated tissue samples, collected from the field at the beginning of any particular study, the decline of radioactive content of tissues serially sampled from the field population, and the rate of radioactive decay of fallout in the environment are similar for samples of skin, GI tract, and muscle. Liver and kidney tissue from the population and individual are similar in decay characteristics but deviate markedly from the rate

of radioactive decay of fallout in the environment. These relationships are not apparent for bone and reflect the buildup or retention of specific isotopes.

#### *Sr<sup>90</sup> contamination levels in Nevada and Utah soils*

Strontium 90 levels of surface 0- to 1-inch soil samples collected in Nevada and Utah in August 1958 ranged from 31.9 to 142 mc/square mile in virgin areas near known fallout midlines and from 7.5 to 22.7 mc/square mile in agricultural areas which did not coincide with fallout midlines.

The Sr<sup>90</sup> contamination levels in agricultural 0- to 1-inch surface soil samples are lower than those of virgin area samples (table 1) probably as a result of both lesser amounts of fallout from Nevada test site activity and subsequent cultivation of the soil. The observed surface levels in agricultural areas are similar to those reported in other areas of the country; however, the levels of Sr<sup>90</sup> in the subsoils are presently unknown.

The assumption that Nevada test site activities represent the major source of Sr<sup>90</sup> at the virgin area locations is supported by Sr<sup>90</sup> percentages of total beta activity. The theoretical percentages for various series tend to be approached by the observed percentages (table 2).

TABLE 1.—Sr<sup>90</sup> levels by fusion analysis at 11 selected areas in Nevada and Utah (date of collection, August 1958)

| Area                                                | Location                          | Sr <sup>90</sup> activity (0-1" depth) |          |
|-----------------------------------------------------|-----------------------------------|----------------------------------------|----------|
|                                                     |                                   | mc/sq mi                               | μmc/g Ca |
| Cultivated agricultural areas:                      |                                   |                                        |          |
| Almo, Nev                                           | 1 mile south                      | 21.3                                   | 6.8      |
| Moapa, Nev                                          | 7.7 miles northwest               | 16.3                                   | 2.5      |
| Riverside, Nev                                      | 0.4 mile south                    | 22.7                                   | 9.6      |
| St. George, Utah                                    | 1 mile southeast                  | 14.4                                   | 4.5      |
| Hurricane, Utah                                     | 1 mile southwest                  | 12.4                                   | 3.5      |
| Enterprise, Utah                                    | 0.7 mile north                    | 7.46                                   | 3.6      |
| Cedar City, Utah                                    | 2 miles southwest of Enoch        | 16.7                                   | 4.6      |
| Vernal, Utah                                        | 4 miles south                     | 13.8                                   | 8.7      |
| Virgin undisturbed area, fallout midline locations: |                                   |                                        |          |
| Moapa, Nev                                          | 8 miles north                     | 142.0                                  | 28.3     |
| Elgin, Nev                                          | 3.8 miles southwest               | 114.0                                  | 140.0    |
| St. George, Utah                                    | 5 miles north                     | 45.6                                   | 406.0    |
| Enterprise, Utah                                    | 9 miles north                     | 41.2                                   | 51.2     |
| Panguitch, Utah                                     | City limit, northwest corner      | 31.9                                   | 14.9     |
| Sunnyside, Utah                                     | 3.1 miles south of Columbia, Utah | 67.2                                   | 202.0    |

TABLE 2.—Observed and theoretical Sr<sup>90</sup> percentages of total activity at locations on midlines of specific detonations

| Area             | Location            | Series          | Shot        | Sr <sup>90</sup> activity as of August 1958 |                           |                                       |
|------------------|---------------------|-----------------|-------------|---------------------------------------------|---------------------------|---------------------------------------|
|                  |                     |                 |             | mc/sq mi                                    | Percent of total activity |                                       |
|                  |                     |                 |             |                                             | Observed <sup>1</sup>     | Theoretical (for series) <sup>2</sup> |
| Moapa, Nev.      | 8 miles north       | Upshot-Knothole | Simon       | 142                                         | 12.2±3.18                 | 18-19                                 |
| St. George, Utah | 5 miles north       | do              | Annie-Simon | 45.6                                        | 3.06±0.10                 | 18-19                                 |
| Elgin, Nev.      | 3.8 miles southwest | Tespot          | Met.        | 114                                         | 6.77±1.15                 | 11-12                                 |
| Enterprise, Utah | 9 miles north       | do              | do          | 41.2                                        | 7.01±3.79                 | 11-12                                 |
| Panguitch, Utah  | City limit          | Plumbbob        | Smoky       | 31.9                                        | 2.36±0.30                 | 2-3.5                                 |
| Columbus, Utah   | 3.1 miles south     | do              | do          | 67.2                                        | 2.57±0.38                 | 2-3.5                                 |

<sup>1</sup> Standard deviation values refer to variation of Sr<sup>90</sup> percentages of 5 surface soil samples at each location.  
<sup>2</sup> Determined from values published by Bolles and Balleau, USNRL-456.

Four soil sampling sites have been subjected to a comparative study of Sr<sup>90</sup> contamination measured by total solubilization following alkali fusion and by leaching with 6 N HCl. The results indicate clearly that in the Nevada-Utah

area total solubilization of soil samples is necessary in order to evaluate area contamination, and that the amounts of Sr<sup>90</sup> leached by 6 N HCl vary at least within the range from 13 to 78 percent of the total present as shown by the following tabulation:

| Location         | Sr <sup>90</sup> —mc/sq mile           |                  | Percent soluble |
|------------------|----------------------------------------|------------------|-----------------|
|                  | Na <sub>2</sub> CO <sub>3</sub> fusion | 6 N HCl leaching |                 |
| Columbus, Utah   | 67.2                                   | 52.8             | 78.6            |
| Enterprise, Utah | 41.2                                   | 7.6              | 18.5            |
| Moapa, Nev.      | 142.0                                  | 18.6             | 13.1            |
| Panguitch, Utah  | 31.9                                   | 16.2             | 50.7            |

#### *Survey of Sr<sup>90</sup> in milk in Nevada and Utah*

A survey is in progress at University of California at Los Angeles relative to Sr<sup>90</sup> levels in milk produced in Nevada and Utah agricultural areas. In addition to analyzing milk samples, soil samples, obtained from pastureland, hayfields, etc., on the farms from which milk was obtained, are being analyzed to determine the levels of Sr<sup>90</sup> contamination associated with the individual milk sources. The following table presents typical data obtained from July and August 1958 sampling of several areas in Nevada and southern Utah.

Comparison of soil and milk strontium 90 levels in representative areas in Nevada and Utah, July and August 1958

| Location         | Soil Sr <sup>90</sup> (0-1" depth) |                            | Milk Sr <sup>90</sup> μmc/g Ca |
|------------------|------------------------------------|----------------------------|--------------------------------|
|                  | mc/sq mi                           | μmc Sr <sup>90</sup> /g Ca |                                |
| Alamo, Nev.      | 21.3                               | 6.8                        | 2.8                            |
| Moapa, Nev.      | 16.3                               | 2.5                        | 1.6                            |
| Cedar City, Utah | 16.7                               | 4.6                        | 3.2                            |
| Hurricane, Utah  | 12.4                               | 3.5                        | 6.4                            |
| St. George, Utah | 14.4                               | 4.5                        | 3.8                            |
| Enterprise, Utah | 7.5                                | 3.6                        | 4.5                            |
| Vernal, Utah     | 13.8                               | 8.7                        | 6.7                            |

<sup>1</sup> Determined by total solution following alkali fusion of surface 1 inch soil sample.

The foregoing data in general serve to point out the fact that the Sr<sup>90</sup> levels in milk produced in this area are lower in relation to the amount of calcium present than is the case with soils by a factor of approximately 1.5-2.0, and that the levels of Sr<sup>90</sup> in the milk are relatively low in relation to the levels of area contamination.

Milk samples were collected in 1957 and 1958 to assess the influence of the Plumbbob test series. Table 3 presents available data.

These data show no consistent relationship between the levels of soil contamination and the Sr<sup>90</sup> content of milk. This lack of agreement may be attributable to a number of factors among which may be included variations in solubility and/or biological availability of the Sr<sup>90</sup>, differences in levels of normal nonradioactive strontium, and actual amounts of calcium in the dairy feeds.

TABLE 3.—Pre- and post-Plumbbob series  $\text{Sr}^{90}$  and  $\text{Cs}^{137}$  content in milk collected from various ranches in Nevada, Utah, and California (analysis by Environmental Radiation Division, University of California at Los Angeles)

| Location         | Date sampled   | Type and origin of feed as indicated by owner of herd  | $\text{Sr}^{90}$<br>$\mu\text{Ci/g Ca}$ | $\text{Cs}^{137}$<br>$\text{d/mi/quart}$ |
|------------------|----------------|--------------------------------------------------------|-----------------------------------------|------------------------------------------|
| Alamo, Nev.      | May 2, 1957    | Idaho hay, St. George concentrate                      | 17.4                                    | 27                                       |
| Do               | Aug. 3, 1957   | No information available                               | 5.3                                     | 75                                       |
| Do               | Oct. 31, 1957  | Alfalfa pasture, St. George concentrate                | 5.0                                     | 44                                       |
| Do               | July —, 1958   | No information                                         | 2.8                                     | —                                        |
| Antimony, Utah   | Sept. 20, 1957 | do                                                     | 13.6                                    | 119                                      |
| Do               | Oct. 21, 1957  | Dry feeding exclusively                                | 10.0                                    | 121                                      |
| Do               | July —, 1958   | No information                                         | 3.5                                     | —                                        |
| Bishop, Calif.   | Nov. 6, 1957   | Hay from local source                                  | 3.2                                     | 32                                       |
| Fremont, Utah    | Sept. 9, 1957  | Hay, 20 percent; pasture, 80 percent; commercial feed. | 12.1                                    | 99                                       |
| Do               | Sept. 21, 1957 | No information                                         | 9.5                                     | 83                                       |
| Do               | Oct. 19, 1957  | Alfalfa pasture, commercial feed                       | 4.9                                     | 56                                       |
| Do               | July —, 1958   | No information                                         | 4.4                                     | —                                        |
| Lund, Nev.       | Nov. 4, 1957   | 1957 hay, alfalfa pasture, local grain                 | 3.2                                     | 71                                       |
| Mesquite, Nev.   | Aug. 2, 1957   | No information                                         | —                                       | 70                                       |
| Do               | Oct. 23, 1957  | Local hay, St. George feed                             | 6.1                                     | 58                                       |
| Milford, Utah    | Apr. 26, 1957  | 1956 hay, home grown grain                             | 3.1                                     | 63                                       |
| Do               | Oct. 26, 1957  | 50 percent pasture, 50 percent 1957 hay, grain.        | 2.7                                     | 29                                       |
| Pahrump, Nev.    | Nov. 1, 1957   | Home grown hay, ensilage, grain                        | 6.0                                     | 31                                       |
| Panguitch, Utah  | Sept. 8, 1957  | Local pasture                                          | 37.3                                    | 159                                      |
| Do               | Sept. 20, 1957 | do                                                     | 17.0                                    | 94                                       |
| Do               | Oct. 21, 1957  | Old hay                                                | 26.2                                    | 182                                      |
| Do               | July —, 1958   | No information                                         | 25.6                                    | —                                        |
| St. George, Utah | Aug. 31, 1957  | 1957 hay, 3d cutting, grain                            | 2.6                                     | 45                                       |
| Do               | Oct. 26, 1957  | 1957 hay and ensilage, grain                           | 4.6                                     | 103                                      |
| Do               | July —, 1958   | No information                                         | 3.8                                     | —                                        |
| Veyo, Utah       | July 8, 1957   | Hay from Enterprise, local pasture                     | 7.2                                     | 88                                       |
| Do               | July 15, 1957  | No information                                         | 8.2                                     | 52                                       |
| Do               | Aug. 3, 1957   | do                                                     | 5.1                                     | 65                                       |
| Do               | Sept. 10, 1957 | Hay from Enterprise and local pasture                  | 4.1                                     | 38                                       |
| Do               | Oct. 27, 1957  | Hay from 1957 cutting                                  | 4.0                                     | 45                                       |
| Do               | July —, 1958   | No information                                         | 2.8                                     | —                                        |

A similar picture regarding the relationship between area contamination and biological burden is apparent where soil and bone  $\text{Sr}^{90}$  levels are compared. Approximately 10 areas have had such a comparison completed. Whereas soil activity levels range from 13.8 to 142 mc./sq. mi., the range of bone activity (rabbits) is from 10-22  $\mu\text{Ci Sr}^{90}/\text{g Ca}$ , with some of the lowest bone levels coinciding with high levels of area contamination. The picture is even more complex if the comparison is made on the basis of  $\mu\text{Ci Sr}^{90}/\text{g Ca}$  in the soil. In this case the soil range is from 2.5 to 406 units.

A survey of  $\text{Sr}^{90}$  levels in the bones of male Big Horn sheep from the Desert Game Range, Clark County, Nev. covering two hunting seasons, 1956 and 1957, or pre- and post-Plumbbob operation has been made. Approximately 20 specimens from each season were analyzed. The mean value for 1956 was 2.8  $\mu\text{Ci Sr}^{90}/\text{g Ca}$ , while the 1957 value was 6.6  $\mu\text{Ci Sr}^{90}/\text{g Ca}$ , or slightly more than double the 1956 value.

A similar survey of deer bones covering Nevada (NE quadrant primarily) more completely gives similar results, with some values ranging up as high as 25  $\mu\text{Ci Sr}^{90}/\text{g Ca}$ . Where samples were obtained both years from the same locality, an increase in  $\text{Sr}^{90}$  during the year, 1957, is apparent.

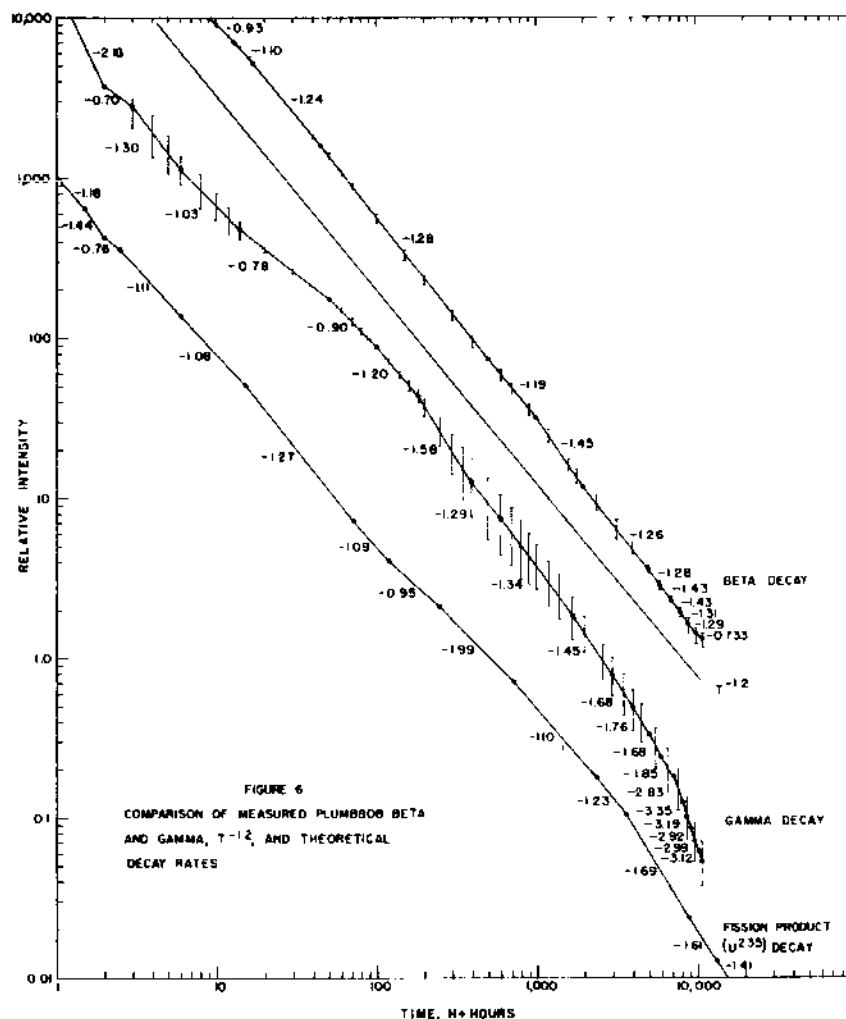
#### Soil-plant factors experimentally determined which affect $\text{Sr}^{90}$ and $\text{Cs}^{137}$ accumulation in crops

Several soil and plant factors influence the availability and accumulation of fission products in plants. Laboratory and greenhouse studies indicate that radiostrontium is most readily accumulated by crop plants from artificially contaminated soils. Only very small amounts of  $\text{Y}^{90}$ ,  $\text{Ru}^{106}$ ,  $\text{Cs}^{137}$ , and  $\text{Ce}^{144}$  were accumulated.

In a short time experiment (21 days), the addition of noncomposted organic matter to soils reduced  $\text{Sr}^{90}$  uptake by barley seedlings. The application of undecomposed organic matter at the levels equivalent to 10, 20, 50, and 100 tons per acre reduced the uptake of  $\text{Sr}^{90}$  12, 30, 50, and 75 percent, respectively. The influence of the organic matter applied was related to its effect on the soil microbial population and to the change in the chemical composition of the soils as the organic matter decomposed.

The addition of lime ( $\text{CaCO}_3$ ) and gypsum ( $\text{CaSO}_4$ ) to acidic soils low in native Ca reduced  $\text{Sr}^{90}$  uptake by plants. Greatest inhibition occurred at treatment levels equivalent to from 2 to 5 tons per acre. At these levels  $\text{CaCO}_3$  reduced  $\text{Sr}^{90}$  uptake about 60 percent;  $\text{CaSO}_4$  caused 80 percent reduction. These Ca amendments to the soil had little or no influence on the uptake of  $\text{Sr}^{90}$  from neutral alkaline soils.

The uptake of  $\text{Cs}^{137}$  occurring as a contaminant increased as the K concentration in the soil was reduced by prolonged cropping. The addition of K to contaminated soils low in potassium content reduced the uptake of  $\text{Cs}^{137}$  by plants.



## FALLOUT FROM NUCLEAR TESTS AT THE NEVADA TEST SITE

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About one megaton of energy from fission has been released at the Nevada Test Site from nuclear test detonations. The total resultant fission product activity, if measured at one hour after formation, would have been about 400-600 billion curies. There was nothing that could be done to lessen the production of radioactive isotopes from a fission reaction, thus the utmost care and skill were required in the conduct of the tests to minimize the deposition of the activity outside the Test Site.

There follows a summary of the data on fallout from nuclear detonations at the Nevada Test Site.

### I. EXTERNAL GAMMA EXPOSURES

Table I summarizes the data on external gamma exposures in areas around the Nevada Test Site resulting from all past nuclear test detonations. Since the estimates are based on potential exposures in areas if persons had continued to live there continuously, full use should be made of the notes at the end of the Table. For example, the Table shows 10.80 roentgens for Dodge Construction Camp, Nevada, but the estimated exposure to persons was about 2.7 roentgens since



no one was living in the area previous to Operation Plumbbob (Spring-Summer 1957). On the other hand, the Table indicates a zero population for Riverside, Nevada which is correct for the present, but during the time of heaviest fallout (Operation Upshot-Knothole Spring 1953) some persons were in the area.

To summarize Table I:

1. The highest estimated exposures were up to about 13 1/2 roentgens for one person and 10 1/2 roentgens for another at Butler Ranch, Nevada.

2. The highest estimated exposure at any "community" (Lincoln Mine) was about 6 roentgens.

3. Between the above two radiation dose levels there might have been up to 30 persons so exposed.

It may be noted that many of the estimated exposures according to Table I are higher than preliminary reports<sup>1</sup>. This has resulted from continuing studies of several factors, i.e. radiological decay rates, weathering effects, instrument cross-calibration and the like. As with any such data there are associated uncertainty factors. The Committee has estimated these as follows:

for doses less than 0.1 roentgen  $\pm$  80%

for doses 0.1 - 1.0 roentgens  $\pm$  60%

for doses greater than 1.0 r  $\pm$  40%

It will also be noted that some areas are included in Table I that did not appear in the preliminary data. After all the monitoring

data were collected, evaluated and plotted, interpolations between data points were made to include these areas.

The map Estimated Radiation Doses presents the highlights of the data in pictorial form.

As one of the monitoring programs, film badges were worn by persons in many localities around the Nevada Test Site. Assuming these were worn properly on the person, they represent one of the best estimates of actual exposures. Of interest is the ratio of these film badge readings to those badges placed out of doors in the same general area. These data are summarized in Table II based on 87 locations. The lower ratios would be expected due in part to shielding effects when persons were indoors. Those with higher ratios are more difficult to explain. One factor is the normal movement of persons with some going to areas of higher contamination for periods of time.

2.  
The information from another study<sup>2</sup> which analyzed data of dose rate readings inside and outside various type structures around the Nevada Test Site during Operation Plumbbob is summarized in Table III.

## II. Environmental Contamination

### A. General

Relatively fresh fission product fallout, such as that originally placed into the troposphere from a nuclear detonation, contains a wide variety of isotopes. The composition (relative percentage of isotopes) varies with time after formation. Also fractionation may occur, i.e. there may be a deviation from the expected isotopic abundance due to the fact that some isotopes have gaseous precursors. However, the percentage of isotopes present may be approximated by the use of such data as contained in Reference Three.

The fallout that occurs around the Nevada Test Site from nuclear detonations at that location does so at relatively short times after an explosion. This radioactive material contains a large percentage of short-lived radioisotopes which contribute significantly to the external gamma dose but little to the accumulated dose accruing from those isotopes internally deposited. This is due to the short half-lives and to the relatively low uptake and deposition of most of these isotopes in the body.

The isotope of principal concern in terms of internal irradiation is strontium-90. It would be desirable to determine the strontium-90 content of fresh fission product activity found associated with foodstuffs and water. The isotopic analysis for this isotope, however, is not a simple and quick procedure. In an understandable desire to

make conservative estimates of potential health hazards, all of the fission product activity found in foods and water has at times been ascribed to strontium-90. This can lead to erroneous evaluations. For example, if fresh fission product activity is measured one week after formation as little as one part in 7000 of this activity might be due to strontium-90 (assuming no fractionation). In making such an approximation one does not intend that it is precise but it does more accurately estimate the strontium-90 content than does the method of ascribing all of the fission product activity to the one isotope. This type of approximation may be more nearly correct for surface contamination on objects (including exposed foodstuffs) and in rainwater, than in waters that have passed through or over soils, since some selective absorption would be expected in the latter case.

As a result of the fallout that occurred in Southern California in the Fall of 1958, such foodstuffs as lettuce, spinach and celery were found to contain gross beta activity (as counted about two weeks after the fallout occurred) amounting to a few - several tens of disintegrations per minute per gram. Yet when five of these samples were later analyzed for strontium-90, the values ranged from 2.71 to 4.9 strontium units - values which are not significantly different from foods grown elsewhere in the country and, in fact, are on the low side of the average. Additional samples are being analyzed and

somewhat higher values will probably be found in some of these, but it would appear that whatever strontium-90 there may have been in the fresh fallout it was not a major addition to that already in the plants (strontium-90 originating from past tests).

#### B. Milk - Soils

Considerable data on contamination of soils, plants and animals have been collected by the Offsite Rad-Safe Group of the Nevada Test Organization under Mr. Oliver Placak of the U. S. Public Health Service and by several projects under Mr. Kermit Larson of the University of California at Los Angeles. These data may be found in the reports from these organizations. The information given here is only a very small part of these data. They were chosen to illustrate the general levels of strontium-90 activity in the environment.

#### Milk

Prior to Operation Plumbbob and again following the completion of that test series sets of milk samples from around the Nevada Test Site were collected and analyzed by Mr. Kermit Larson of UCLA. With one possible exception (Panguitch, Utah) the values are not significantly different from those found in most other localities in the United States. These data are summarized in Table IV.

Milk collections have also been made in the Glendale, Nevada and the St. George-Cedar City, Utah areas by the Offsite Rad-Safe Group and analyzed by the Division of Radiological Research, Robert A. Taft

Sanitary Engineering Center, Public Health Service, Cincinnati, Ohio. These data are summarized in Table V. These values are no higher than for most other areas sampled in the United States.

#### Soils

Soil samples from areas around the Nevada Test Site experiencing some of the heaviest fallout from tests at the Nevada Test Site were collected following Operation Plumbbob (1957) and are being analyzed for their strontium-90 content. Values from cultivated lands are given in Table VI. Some preliminary data from non-tilled soils show, in general, higher values. These will be reported when completed.

### C. Concentration of Activity in the Air

The increase of small amounts of fallout debris in the air can be readily determined by the use of standard air sampling techniques. The sensitivity of this method provides an excellent monitor to determine the time of the appearance and the relative amounts of fallout. At the same time these data are subject to misinterpretations in terms of a "health hazard". For example, concentrations for short periods of fallout material in the air in amounts hundreds of times above background may not constitute a serious situation. This may be illustrated by the fallout that occurred in the Los Angeles, California area in the Fall of 1958. (See California Fallout Data report below.)

The peak concentrations of radioactivity in the air over Los Angeles were due principally to the nuclear detonations at the Nevada Test Site on October 29, 1958. Mixed with this there was a smaller amount of longer-lived material originating from either previous detonations in Nevada or from the Russian explosions, or both. The recurrence of higher than normal activities in the air the first week in November was undoubtedly due to the meteorology conditions present whereby the air masses passed seaward over Los Angeles, then returned and remained in the general area, accompanied by an inversion layer.

The concentration of fallout debris in the air peaked at 700 micromicrocuries per cubic meter on October 30, 1958, dropped to

38 of these units on November 1, and reached a second high of 370 units on November 3rd. Prior to this fallout the "background values" were about 1 - 2 micromicrocuries per cubic meter.

The biological evaluation of such data is quite tenuous, yet some estimates may be made. Using the methods described in Reference Four, it was estimated that the dose to the lungs from inhalation of air during the week of highest fallout activity in the air amounted to a few millirems. During the same period of time the estimated exposure to the lungs from naturally occurring radiation substances in the air (radon and thoron, together with their daughter products) probably was several times this amount.

In addition to irradiation of the lungs there is the probability that some of the activity may find its way to other organs of the body. However, fallout around the Nevada Test Site has been found to be quite insoluble.<sup>5</sup> Only rough estimates can be made but these indicate that the strontium-90 that might be deposited in the body (other than the lungs) by the inhalation route, even on the day of peak air concentrations (700 micromicrocuries per cubic meter) would be only a very small quantity compared to the normal daily strontium-90 intake by ingestion of foodstuffs.

Concurrent with the fallout debris in the air over Los Angeles there was a deposition of some of this material on the ground. Fortunately, automatic gamma recorders were in operation and they

showed that the total external gamma exposure from this fallout was a few tenths of a milliroentgen at most - an amount received every day or two from naturally occurring radioactive substances in our environment.

The highest measured concentration of radioactive fallout in the air over populated areas of the United States was at St. George, Utah on May 19-20, 1953 (as previously reported in the Congressional Hearings on fallout - 1957). A recalculation of these data indicates<sup>4</sup> a lung dose of about 230 millirems<sup>5</sup>. The radiation exposure to the lungs from inhalation of naturally occurring radioactive substances varies from place to place and from time to time, but a value of about 25 millirems per week is a rough estimate. This is a lower estimate than was previously used<sup>6</sup>. Knowledge on radiation doses to the lungs from naturally occurring radioactive substances in the air is still sparse, and such estimates that have been made encompass a rather wide range. A more conservative value of 25 millirems per week is used here. Thus, the calculated exposure to the lungs from inhalation of fallout debris in the air at St. George might have been equivalent to that received in about 10 weeks from naturally occurring radioactive substances in the air.

#### D. Concentration in Water

Customarily, only gross beta counts have been made on fallout activity in water. Without further analyses one can only make estimates as to isotopic content, and thus potential radiation doses. One method for doing this is given in Reference Five.

The highest measured concentration of fallout activity in a potential drinking water supply (this is not a known supply for humans) was at upper Pahrnagat Lake, Nevada during the 1955 test series at the Nevada Test Site amounting to  $1.4 \times 10^{-4}$  microcuries per milliliter at three days after the detonation (as previously reported in the Congressional Hearings on fallout - 1957). If this water had been stored and used as a sole supply for 70 years, the total internal doses may be estimated as follows:

|                                                                                   |           |
|-----------------------------------------------------------------------------------|-----------|
| Bones                                                                             | -1.0 rad  |
| Lower large intestine<br>(with lesser doses to<br>other parts of the GI<br>tract) | -0.25 rad |
| Thyroid                                                                           | -0.25 rad |

#### E. More Distant Fallout

Nuclear detonations occurring on or near the ground result in relatively heavy nearby fallout. Conversely, there is some evidence that nuclear detonations occurring from balloons suspended well above the ground may produce more fallout at greater distances than would surface bursts. It has also been shown that rain will bring down fallout present in the troposphere. Following several nuclear detonations of devices suspended from balloons during Operation Plumbob (Spring-Summer 1957), the trajectories were over the North Central States. There was precipitation in many of these areas during passage of these trajectories.

The trajectories as given by the accompanying maps were prepared by the Special Projects Section of the U. S. Weather Bureau under Dr. Lester Machta. These trajectories do not represent actual measurements of the activity in the air since the relatively rapid radiological decay and the dilution factor usually make it impossible to trace the activity for more than a few hundred miles from the test site by aircraft. Rather, the trajectories represent a series of computations as to probable movements of air (together with any contained activity).

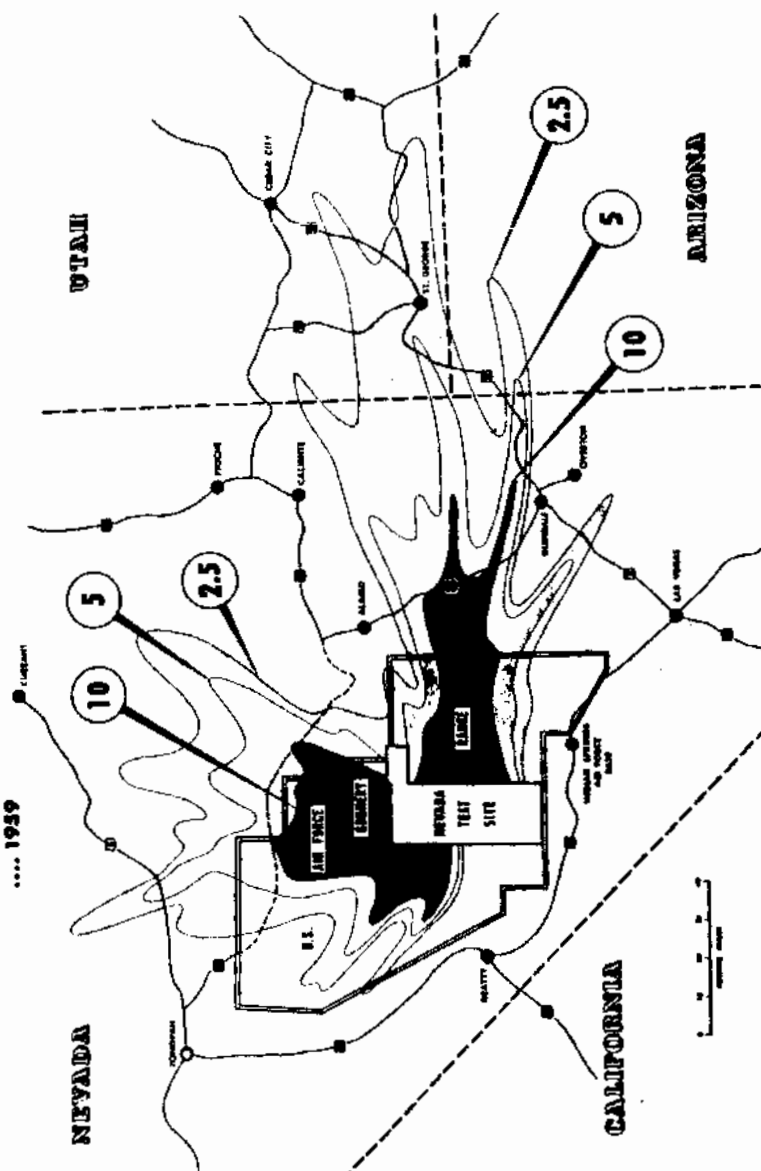
Table VII shows the relatively high strontium-90 in wheat collections in Minnesota during 1957. Although the data are not extensive enough to be conclusive, it will be noted that there was a higher average value of strontium-90 in wheat for 1957 (the time of Operation Plumbbob) than 1956 or 1958. Additional samples of wheat are being collected and analyzed.

Better estimates are needed as to the relative methods whereby the wheat was contaminated, i.e. by surface contamination or by soil uptake. Tropospheric fallout probably contributes heavily to surface contamination, and since it has a half-time of residence of about one month, this effect should now have essentially ceased from all past tests. A factor in the opposite direction is the increase of strontium-90 in the soils - and thus plant uptake - since strontium-90 is continually dropping from the stratosphere. It is hoped that the 1959 samples of wheat will shed further light on this factor.

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# ESTIMATED RADIATION DOSES (Roentgens) FROM ALL NUCLEAR TESTS .... 1959



a.

TABLE I.

## Estimated Radiation Doses (Roentgens)

|                          |                   | <u>Pre-Plumbob</u>  | <u>Plumbob</u> | <u>Hardack II</u> | <u>Cumulative</u> |
|--------------------------|-------------------|---------------------|----------------|-------------------|-------------------|
| <u>Location</u>          | <u>Population</u> | <u>ARIZONA</u>      |                |                   |                   |
| Beaver Dam               | 5                 | 2.00                | 0.30           | - <sup>b</sup>    | 2.30              |
| Big Bend Ranch           | 5                 | (2.00) <sup>c</sup> | 0.19           | -                 | 2.19              |
| Bullhead                 | 500               | -                   | 0.02           | -                 | 0.02              |
| Catherine Ranger Station | d.                | -                   | -              | -                 | -                 |
| Chloride                 | 160               | -                   | 0.02           | -                 | 0.02              |
| Davis Dam                | 15                | -                   | -              | -                 | -                 |
| Grasshopper Junction     | 2                 | -                   | 0.03           | -                 | 0.03              |
| Hackberry                | 100               | -                   | 0.01           | -                 | 0.01              |
| Hughes Ranch             | Transient         | (2.00)              | 0.30           | -                 | 2.30              |
| Kingman                  | 5,500             | 0.03                | 0.01           | -                 | 0.04              |
| Lake Mohave              | 2 <sup>1/</sup>   | -                   | 0.02           | -                 | 0.02              |
| Littlefield              | 44                | 1.60                | 0.32           | -                 | 1.92              |
| Mount Trumbull           | 100               | 0.16                | -              | -                 | 0.16              |
| Oatman                   | 40                | -                   | -              | -                 | -                 |
| Peach Spring             | 600               | -                   | -              | -                 | -                 |
| Short Creek              | 90                | 1.60                | -              | -                 | 1.60              |
| Topock                   | 80                | -                   | -              | -                 | -                 |
| Truxton                  | 26                | -                   | -              | -                 | -                 |
| Valentine                | 50                | -                   | 0.01           | -                 | 0.01              |
| Wapapai                  | 15                | -                   | -              | -                 | -                 |
| Warm Springs             | d.                | -                   | -              | -                 | -                 |
| Willow Beach             | 5                 | -                   | -              | -                 | -                 |
| Wolf Hole                | 5                 | 1.30                | -              | -                 | 1.30              |
| Yucca                    | 150               | -                   | -              | -                 | -                 |

a. Prepared by a Committee composed of the following members:

A. Vay Shelton, Chairman, Lawrence Radiation Laboratory, University of California.  
 Roscoe H. Gouke, Albuquerque Operations Office, U. S. Atomic Energy Commission  
 (On loan from the U. S. Public Health Service)  
 William R. Kennedy, Los Alamos Scientific Laboratory  
 Kermit M. Larson, University of California, Los Angeles  
 Kenneth M. Nagler, U. S. Weather Bureau  
 Oliver R. Placsek, Las Vegas Branch Office, U. S. Atomic Energy Commission  
 (Officer-in-charge U. S. Public Health Service)

b. A dash implies no fallout or fallout not readily distinguishable from background radiation.

c. Parentheses indicate that the community was not included in the October, 1956, list of Pre-Plumbob doses.

d. Population figures not available.

NOTE: Footnotes concerning populations of communities are at end of this table.



CALIFORNIAEstimated Radiation Doses (Roentgens)

| <u>Location</u>                    | <u>Population</u> | <u>Pre-Plumbbob</u> | <u>Plumbbob</u> | <u>Hardtack</u> | <u>Cumulative</u> |
|------------------------------------|-------------------|---------------------|-----------------|-----------------|-------------------|
| Amboy                              | 1,004             | -                   | -               | -               | -                 |
| Baker                              | 726               | -                   | 0.03            | -               | 0.03              |
| Barstow                            | 10,017            | -                   | 0.01            | -               | 0.01              |
| Benton Station                     | 300               | -                   | 0.07            | -               | 0.07              |
| Big Pine                           | 556               | -                   | 0.03            | -               | 0.03              |
| Bishop                             | 2,891             | -                   | 0.06            | -               | 0.06              |
| Boron                              | 592               | -                   | -               | -               | -                 |
| Camp Irwin                         | Variable          | -                   | -               | -               | -                 |
| Cantil                             | 100               | -                   | -               | -               | -                 |
| Cartago                            | 126               | -                   | 0.03            | -               | 0.03              |
| Chalfant                           | 25                | -                   | 0.10            | -               | 0.10              |
| China Lake                         | 10,000            | -                   | -               | -               | -                 |
| Crest View                         | 25                | -                   | -               | -               | -                 |
| Daggett                            | 525               | -                   | -               | -               | -                 |
| Death Valley Junction              | 20                | -                   | -               | 0.15            | 0.15              |
| Deep Springs                       | 100               | -                   | 0.03            | -               | 0.03              |
| Emigrant Springs<br>Ranger Station | 2                 | -                   | 0.01            | 0.08            | 0.09              |
| Essex                              | 75                | -                   | 0.02            | -               | 0.02              |
| Four Corners                       | 4                 | -                   | -               | -               | -                 |
| Furnace Creek                      | 50                | -                   | -               | 0.15            | 0.15              |
| Hinkley                            | 780               | -                   | -               | -               | -                 |
| Independence                       | 875               | -                   | 0.02            | -               | 0.02              |
| Inyokern                           | 600               | -                   | -               | -               | -                 |
| Johannesburg                       | 300               | -                   | 0.03            | -               | 0.03              |
| Kaleo                              | 271               | -                   | 0.03            | -               | 0.03              |
| Lemo                               | 72                | -                   | 0.07            | -               | 0.07              |
| Lanwood                            | 2,600             | -                   | 0.01            | -               | 0.01              |
| Littlelake                         | 32                | -                   | -               | -               | -                 |
| Loma Pine                          | 1,415             | -                   | 0.03            | 0.05            | 0.08              |

CALIFORNIAEstimated Radiation Doses (Roentgens)

| <u>Location</u> | <u>Population</u> | <u>Pre-Plumbbob</u> | <u>Plumbbob</u> | <u>Hardtack</u> | <u>Cumulative</u> |
|-----------------|-------------------|---------------------|-----------------|-----------------|-------------------|
| Ludlow          | 250               | -                   | -               | -               | -                 |
| Manix           | 10                | -                   | -               | -               | -                 |
| Mojave          | 2,055             | -                   | -               | -               | -                 |
| Mountain Pass   | 10                | -                   | -               | -               | -                 |
| Needles         | 5,480             | -                   | -               | -               | -                 |
| Newberry        | 700               | -                   | -               | -               | -                 |
| Oasis           | 12                | -                   | 0.10            | -               | 0.10              |
| Olancha         | 275               | -                   | 0.03            | -               | 0.03              |
| Randenburg      | 281               | -                   | -               | -               | -                 |
| Red Mountain    | 320               | -                   | 0.03            | -               | 0.03              |
| Ridgecrest      | 4,000             | -                   | 0.02            | -               | 0.02              |
| Ryan Mine       | 1                 | -                   | 0.06            | 0.15            | 0.21              |
| Shoshone        | 100               | -                   | -               | -               | -                 |
| Silver Lake     | 10                | -                   | 0.05            | -               | 0.05              |
| South Malheur   | 25                | -                   | -               | -               | -                 |
| Stovepipe Wells | 2                 | -                   | 0.01            | 0.05            | 0.06              |
| Tecopa          | 25                | -                   | -               | -               | -                 |
| Tom's Place     | Variable          | -                   | 0.02            | -               | 0.02              |
| Troms           | 3,500             | -                   | -               | -               | -                 |
| Wheaton Springs | 4                 | -                   | -               | -               | -                 |
| Yermo           | 700               | -                   | 0.01            | -               | 0.01              |
| ZZZZ Springs    | 40                | -                   | -               | -               | -                 |

NEVADAEstimated Radiation Doses (Roentgens)

| <u>Location</u>        | <u>Population</u>      | <u>Pre-Plumbbob</u> | <u>Plumbbob</u> | <u>Hardtack</u> | <u>Cumulative</u> |
|------------------------|------------------------|---------------------|-----------------|-----------------|-------------------|
| Ash Mine               | 4 - 12                 | (0.50)              | 2.90            | -               | 3.40              |
| Acorn                  | 10                     | 3.00                | -               | -               | 3.00              |
| Adam's Ranch           | d.                     | (1.00)              | 0.37            | 0.80            | 2.17              |
| Alamo                  | 250                    | 1.30                | 0.04            | 0.05            | 1.39              |
| Apex                   | 50 <sup>2/</sup>       | 0.10                | 0.03            | -               | 0.13              |
| Ash Meadows            | 8                      | 0.05                | 0.01            | 0.15            | 0.21              |
| Ash Springs            | 5                      | 0.60                | 0.06            | -               | 0.66              |
| Atlanta                | 2                      | (0.30)              | 0.26            | -               | 0.56              |
| Austin                 | 520                    | 0.05                | 0.15            | -               | 0.20              |
| Bebbitt                | 2,464                  | -                   | 0.23            | 0.05            | 0.28              |
| Baker                  | 60                     | 0.80                | 0.25            | -               | 1.05              |
| Barclay                | 10                     | 2.00                | 0.04            | -               | 2.04              |
| Bardoll Ranch          | 4 <sup>3/</sup>        | (1.70)              | 0.26            | 0.08            | 2.04              |
| Basalt                 | 8                      | -                   | 0.15            | 0.05            | 0.20              |
| Betty                  | 550                    | 0.05                | 0.11            | 0.05            | 0.21              |
| Bisbee Ranch           | 3                      | (1.19)              | 0.47            | 0.08            | 1.74              |
| Belmont                | 6                      | (0.10)              | 1.10            | 0.05            | 1.25              |
| Blue Diamond           | 400                    | (0.05)              | -               | -               | 0.05              |
| Blue Eagle School      | 11                     | (1.04)              | 0.46            | 0.05            | 1.55              |
| Bonanza Boy Scout Camp | Variable <sup>4/</sup> | (0.12)              | -               | -               | 0.12              |
| Bond Ranch             | d.                     | (0.05)              | 0.70            | -               | 0.75              |
| Boulder City           | 4,000                  | 0.08                | -               | -               | 0.08              |
| Royd                   | Variable <sup>5/</sup> | (1.50)              | 0.04            | -               | 1.54              |
| Bristol Silver Mine    | 25 - 50                | (0.64)              | 0.06            | 0.08            | 0.78              |
| Buckhorn Ranch (US 93) | 12                     | 0.90                | 0.08            | -               | 0.98              |
| Bunkerville            | 250                    | 4.30                | 0.17            | 0.05            | 4.52              |
| Butler Ranch           | 2 <sup>1/2</sup>       | (8.40)              | 6.60            | -               | 15.00             |

NEVADAEstimated Radiation Doses (Roentgens)

| <u>Location</u>                     | <u>Population</u>      | <u>Pre-Plumbbob</u> | <u>Plumbbob</u> | <u>Hardtack</u> | <u>Cumulative</u> |
|-------------------------------------|------------------------|---------------------|-----------------|-----------------|-------------------|
| Cactus Springs                      | 18                     | 0.03                | 0.05            | -               | 0.08              |
| Caliente                            | 970                    | 0.70                | 0.01            | 0.05            | 0.76              |
| Carp                                | 25                     | 3.60                | 0.30            | -               | 3.90              |
| Cassidon Mine                       | 40 - 147               | (0.70)              | 0.02            | -               | 0.72              |
| Charleston Lodge                    | 60                     | 0.15                | -               | -               | 0.15              |
| Cherry Creek                        | 112                    | (0.26)              | 0.24            | -               | 0.50              |
| Clark's Station                     | 0- 5                   | 0.80                | 0.81            | -               | 1.61              |
| Cloud                               | Variable <sup>5/</sup> | (3.00)              | 0.65            | -               | 3.65              |
| Coaldale                            | 25                     | -                   | 0.88            | 0.10            | 0.98              |
| Cole & Dolan Ranch                  | 3                      | (0.50)              | 0.26            | 0.05            | 0.81              |
| Corn Creek                          | 11                     | (0.40)              | -               | -               | 0.40              |
| Cove                                | 20                     | (0.55)              | 0.30            | -               | 0.85              |
| Crestline                           | 22                     | 0.70                | -               | -               | 0.70              |
| Crystal                             | 5 <sup>7/</sup>        | 4.00                | 0.06            | -               | 4.06              |
| Currant                             | 75                     | 0.50                | 0.33            | -               | 0.83              |
| Dalmue                              | 7                      | (0.60)              | 0.01            | -               | 0.61              |
| Desert Rock                         | Variable <sup>8/</sup> | 0.05                | 0.02            | 0.08            | 0.15              |
| Dodge Construction Camp             | 175 <sup>9/</sup>      | (8.00)              | 2.70            | 0.10            | 10.80             |
| Donahue Ranch                       | 4                      | (0.25)              | 0.05            | 0.05            | 0.35              |
| Dry Lake                            | 20                     | 1.00                | 0.03            | -               | 1.03              |
| Duckwater                           | 50                     | 0.80                | 0.21            | -               | 1.01              |
| D-X Ranch                           | d.                     | (0.85)              | 0.20            | -               | 1.05              |
| Dyer                                | 35                     | -                   | 0.13            | 0.05            | 0.18              |
| East Ely                            | 1,000                  | 0.60                | 0.55            | 0.05            | 1.20              |
| El Dorado                           | 3                      | (0.45)              | 0.60            | -               | 1.05              |
| Eldridge Ranch<br>(N. of Eureka)    | 4                      | (0.20)              | 0.34            | -               | 0.54              |
| Eldridge Ranch<br>(Mt. Wheeler Inn) | d.                     | (0.85)              | 0.13            | -               | 0.98              |
| Elgin                               | 30                     | 3.50                | 0.06            | -               | 3.56              |
| Ely                                 | 3,558                  | 0.60                | 0.55            | 0.05            | 1.20              |

## NEVADA

## Estimated Radiation Doses (Roentgens)

| Location                   | Population             | Pre-Plumbbob | Plumbbob | Hardtack | Cumulative |
|----------------------------|------------------------|--------------|----------|----------|------------|
| Etna                       | Variable <sup>5/</sup> | (0.80)       | 0.02     | -        | 0.82       |
| Eureka                     | 500                    | 0.20         | 0.60     | 0.05     | 0.85       |
| Fallini Ranch              | 15                     | 0.80         | 1.10     | 0.08     | 1.98       |
| Fallon                     | 2,400                  | -            | 0.14     | -        | 0.14       |
| Fish Creek Ranch           | 4.                     | (0.50)       | 0.60     | 0.05     | 1.15       |
| Gabbs                      | 625                    | -            | 0.38     | -        | 0.38       |
| Galt                       | Variable <sup>5/</sup> | (6.00)       | 4.90     | -        | 10.90      |
| Garret                     | Variable <sup>5/</sup> | (0.85)       | 0.05     | -        | 0.90       |
| Geyser Maintenance Station | 10                     | (1.00)       | 0.42     | -        | 1.42       |
| Geyser Ranch               | 5                      | (1.05)       | 0.50     | -        | 1.55       |
| Glendale                   | 75                     | 0.70         | 0.10     | 0.05     | 0.85       |
| Goldfield                  | 220                    | 0            | 1.10     | 0.10     | 1.20       |
| Goldpoint                  | 10                     | (0.90)       | 0.30     | 0.10     | 1.30       |
| Goodsprings                | 160                    | -            | -        | -        | -          |
| Groom Mine                 | 0 <sup>10/</sup>       | 2.00         | 2.80     | 0.10     | 4.90       |
| Gubler Ranch               | 4.                     | (0.90)       | 0.44     | 0.05     | 1.39       |
| Hawthorne                  | 1,861                  | -            | 0.23     | 0.05     | 0.28       |
| Henderson                  | 14,000                 | 0.02         | -        | -        | 0.02       |
| Hiko                       | 55                     | 1.00         | 0.08     | -        | 1.08       |
| Hollinger's Ranch          | 1                      | (0.30)       | 0.02     | 0.05     | 0.37       |
| Hoover Dam                 | 4.                     | 0.05         | -        | -        | 0.05       |
| Hoya                       | Variable <sup>5/</sup> | (3.70)       | 2.20     | -        | 5.90       |
| Indian Creek Ranch         | 4.                     | (0.80)       | 0.18     | -        | 0.98       |
| Indian Springs             | 2,650 <sup>11/</sup>   | 0.05         | 0.10     | -        | 0.15       |
| Ione                       | 40                     | -            | 0.24     | -        | 0.24       |
| Johnnie                    | 5                      | 0            | -        | -        | -          |
| Kimberly                   | 120                    | 0.50         | 0.37     | 0.05     | 0.92       |
| Kyle                       | Variable <sup>5/</sup> | (3.20)       | 0.26     | -        | 3.46       |

## NEVADA

## Estimated Radiation Doses (Roentgens)

| Location                 | Population              | Pre-Plumbbob | Plumbbob | Hardtack | Cumulative |
|--------------------------|-------------------------|--------------|----------|----------|------------|
| Laboard Ranch            | x                       | (0.06)       | 0.39     | -        | 0.45       |
| Lake Mead Base           | 5                       | 0.05         | 0.04     | -        | 0.09       |
| Lane City                | 40                      | (0.55)       | 0.38     | 0.05     | 0.98       |
| Las Vegas                | 47,000                  | 0.20         | 0.01     | -        | 0.21       |
| Lathrop Wells            | 9 - 15                  | 0.05         | 0.03     | 0.08     | 0.16       |
| Lehman Caves             | Variable <sup>12/</sup> | (0.95)       | 0.25     | -        | 1.20       |
| Leith                    | Variable <sup>5/</sup>  | (3.00)       | 0.32     | -        | 3.32       |
| Lida                     | 25                      | (0.50)       | 0.32     | 0.05     | 0.87       |
| Lida Junction            | 3                       | (0.40)       | 0.78     | 0.10     | 1.28       |
| Lincoln Mine             | 100-500                 | 4.00         | 1.90     | 0.05     | 5.95       |
| Lockes                   | 4                       | 1.30         | 0.31     | -        | 1.61       |
| Logandale                | 300                     | 0.40         | 0.16     | -        | 0.56       |
| Lund                     | 250                     | 0.80         | 0.44     | 0.05     | 1.29       |
| Luning                   | 50                      | -            | 0.44     | 0.05     | 0.49       |
| MM Mine                  | 2                       | (0.50)       | 2.90     | -        | 3.40       |
| Manhattan                | 42                      | (0.08)       | 0.26     | 0.05     | 0.39       |
| McGill                   | 2,297                   | 0.40         | 0.32     | 0.05     | 0.77       |
| Mercury                  | 300-3,500               | 0.10         | 0.02     | 0.10     | 0.22       |
| Mesquite                 | 590                     | 1.80         | 0.24     | 0.05     | 2.09       |
| Millatt                  | 5                       | (0.04)       | 0.40     | -        | 0.44       |
| Mine                     | 450                     | -            | 0.50     | 0.08     | 0.58       |
| Moapa                    | 52                      | 0.80         | 0.10     | 0.05     | 0.95       |
| Moapa Indian Reservation | 100-150                 | (0.80)       | 0.17     | -        | 0.97       |
| Moon River Ranch         | 3                       | (1.48)       | 0.52     | 0.08     | 2.08       |
| Mouats Ranch             | 4.                      | (0.85)       | (0.24)   | -        | 1.09       |
| Nellis Air Force Base    | 8,000                   | 0.05         | -        | -        | 0.05       |
| Nelson                   | 100                     | -            | -        | -        | -          |
| Nivloc                   | 250                     | -            | 0.35     | 0.08     | 0.43       |
| North Las Vegas          | 13,000                  | 0.20         | -        | -        | 0.20       |

## NEVADA

## Estimated Radiation Doses (Roentgens)

|                                 |                        | Pre-Plumbbob | Plumbbob | Hardtack | Cumulative |
|---------------------------------|------------------------|--------------|----------|----------|------------|
| Location                        | Population             |              |          |          |            |
| Nyala                           | 6                      | 1.70         | 0.28     | 0.08     | 2.06       |
| Overton                         | 750                    | 0.35         | 0.08     | -        | 0.43       |
| Pahrump                         | 89                     | 0.20         | -        | -        | 0.20       |
| Pahrump Mining Co.              | d.                     | (0.09)       | 0.01     | -        | 0.10       |
| Panaca                          | 500                    | 0.65         | 0.01     | -        | 0.66       |
| Parson's Ranch                  | 6 - 8                  | (0.10)       | 0.25     | 0.10     | 0.45       |
| Pioche                          | 1,392                  | 0.70         | 0.04     | -        | 0.74       |
| Pittman                         | d.                     | (0.10)       | -        | -        | 0.10       |
| Pony Springs                    | d.                     | (0.65)       | 0.45     | 0.08     | 1.18       |
| Pop's Oasis                     | d.                     | -            | -        | -        | -          |
| Potts                           | 17                     | (0.20)       | 0.19     | -        | 0.39       |
| Praston                         | 60                     | 0.70         | 0.48     | 0.05     | 1.23       |
| Rattlesnake Maintenance Station | 4                      | (0.75)       | 0.80     | 0.10     | 1.65       |
| Reed                            | 0 <sup>12/</sup>       | 4.00         | 2.66     | 0.08     | 6.74       |
| Reveille Hill                   | 0 <sup>12/</sup>       | (0.70)       | 4.70     | 0.10     | 5.50       |
| Riverside                       | 0 <sup>12/</sup>       | 7.80         | 0.10     | 0.05     | 7.95       |
| Rhyolite                        | 7                      | -            | 0.06     | 0.05     | 0.11       |
| Rogers Ranch                    | 10                     | (0.76)       | 0.21     | 0.05     | 1.02       |
| Rose Valley                     | 10                     | (0.65)       | -        | -        | 0.65       |
| Round Mountain                  | 200                    | 0.05         | 0.36     | 0.08     | 0.49       |
| Rox                             | Variable <sup>3/</sup> | 3.00         | 0.30     | -        | 3.30       |
| Ruby Hill Mine                  | 50                     | (0.18)       | 0.65     | 0.05     | 0.88       |
| Ruth                            | 1,244                  | 0.50         | 0.40     | 0.05     | 0.95       |
| Sarcobatus                      | 3                      | (0.10)       | 0.08     | 0.05     | 0.23       |
| Schurz                          | 100                    | -            | 0.22     | -        | 0.22       |
| Searchlight                     | 150                    | -            | 0.08     | -        | 0.08       |
| Searls Ranch                    | 16                     | (0.70)       | 0.23     | 0.05     | 0.98       |
| Seven L. Ranch                  | 1                      | (0.40)       | 0.02     | -        | 0.42       |

## NEVADA

## Estimated Radiation Doses (Roentgens)

|                        |                        | Pre-Plumbbob | Plumbbob | Hardtack | Cumulative |
|------------------------|------------------------|--------------|----------|----------|------------|
| Location               | Population             |              |          |          |            |
| Sharps (Adaven)        | 25                     | 1.20         | 0.41     | 0.08     | 1.69       |
| Shoshone               | 250                    | 0.70         | 0.24     | -        | 0.94       |
| Silver Peak            | 7                      | -            | 0.65     | 0.10     | 0.75       |
| South Paw Mine         | 3                      | (1.00)       | 0.79     | 0.05     | 1.84       |
| Springdale             | 15                     | 0.02         | 0.04     | 0.05     | 0.11       |
| State Line             | 90                     | -            | -        | -        | -          |
| Steward, R. Ranch      | 6                      | (0.70)       | 0.52     | 0.08     | 1.30       |
| Stine                  | Variable <sup>3/</sup> | (1.10)       | 0.06     | -        | 1.16       |
| Stone Cabin Ranch      | 8                      | (0.60)       | 0.37     | 0.05     | 1.02       |
| Sunnyside              | 26                     | 1.20         | 0.48     | 0.05     | 1.73       |
| Swallow Ranch          | d.                     | (0.80)       | 0.22     | -        | 1.02       |
| Tonopah                | 1,375                  | 0            | 0.98     | 0.10     | 1.08       |
| Tonopah Airport        | 4                      | -            | 0.70     | 0.10     | 0.80       |
| Uhaldi Ranch           | 5 - 8                  | (1.33)       | 0.47     | 0.08     | 1.88       |
| Urretias Ranch         | d.                     | (1.10)       | 0.63     | 0.05     | 1.78       |
| Ursine                 | 25                     | 0.60         | 0.01     | -        | 0.61       |
| Vigo                   | Variable <sup>3/</sup> | (3.00)       | 0.52     | -        | 3.52       |
| Walch Pine Creek Ranch | 4 - 6                  | (2.25)       | 0.45     | 0.08     | 2.78       |
| Warm Springs           | 55                     | 0.50         | 0.35     | 0.08     | 0.93       |
| Warm Springs Ranch     | 56 <sup>16/</sup>      | 1.00         | 0.23     | -        | 1.23       |
| Watertown              | 300 <sup>17/</sup>     | (2.40)       | (1.30)   | 0.10     | 3.80       |
| Whipple Ranch          | 10                     | (1.00)       | 0.10     | -        | 1.10       |
| Whitney                | 78                     | 00           | -        | -        | -          |

## UTAH

## Estimated Radiation Doses (Roentgens)

| Location                          | Population              | Pre-Plumbbob | Plumbbob | Hardtack | Cumulative |
|-----------------------------------|-------------------------|--------------|----------|----------|------------|
| Alamogordo                        | 98                      | (0.23)       | -        | -        | 0.23       |
| Alton                             | 154                     | 0.80         | 0.03     | -        | 0.83       |
| Anderson Junction                 | 17                      | 1.20         | 0.68     | -        | 1.88       |
| Bear Valley Junction              | 10                      | 0.40         | 0.55     | -        | 0.95       |
| Beaver                            | 1,685                   | 0.25         | -        | -        | 0.25       |
| Beryl                             | 15                      | 0.50         | 0.03     | -        | 0.53       |
| Beryl Junction                    | 8                       | 1.00         | 0.05     | -        | 1.05       |
| Black Rock                        | 9                       | (0.05)       | -        | -        | 0.05       |
| Bryce Canyon                      | Variable <sup>12/</sup> | (0.55)       | 0.01     | -        | 0.56       |
| Cedar City                        | 6,106                   | 0.40         | 0.24     | -        | 0.64       |
| Central                           | 49                      | (1.50)       | 0.41     | -        | 1.91       |
| Cove Fort                         | 8                       | 0.07         | -        | -        | 0.07       |
| Desert Range Experimental Station | 5                       | (0.10)       | -        | -        | 0.10       |
| Duck Creek Forest Camp            | d.                      | (0.90)       | 0.17     | -        | 1.07       |
| Enoch                             | 250                     | (0.50)       | 0.04     | -        | 0.54       |
| Enterprise                        | 800                     | 0.70         | 0.09     | -        | 0.79       |
| Garrison                          | 125                     | 0.70         | 0.18     | -        | 0.88       |
| Glendale                          | 275                     | (0.24)       | -        | -        | 0.24       |
| Greenville                        | 173                     | (0.24)       | -        | -        | 0.24       |
| Gunlock                           | 127                     | 2.60         | 0.52     | 0        | 3.12       |
| Hamilton Fort                     | 26                      | 0.60         | 0.20     | -        | 0.80       |
| Hamlin Valley                     | Variable                | (0.50)       | 0.01     | -        | 0.51       |
| Hatch                             | 24                      | (0.50)       | 0.14     | -        | 0.64       |
| Hilldale                          | 10                      | (0.30)       | 0.14     | -        | 0.44       |
| Hurricane                         | 1,375                   | 4.20         | 0.15     | -        | 4.35       |
| Kanab                             | 1,900                   | 1.60         | 0.02     | -        | 1.62       |
| Kanarrville                       | 263                     | 1.20         | 0.73     | -        | 1.93       |
| Kanosh                            | 476                     | (0.05)       | -        | -        | 0.05       |
| La Verkin                         | 387                     | (3.50)       | 0.16     | -        | 3.66       |
| Lands                             | 215                     | 3.00         | 0.70     | -        | 3.70       |

## UTAH

## Estimated Radiation Doses (Roentgens)

| Location                  | Population | Pre-Plumbbob | Plumbbob | Hardtack | Cumulative |
|---------------------------|------------|--------------|----------|----------|------------|
| Long Valley Junction      | 10         | 0.80         | 0.07     | -        | 0.87       |
| Lund                      | 75         | 0.50         | -        | -        | 0.50       |
| Manderfield               | 62         | (0.20)       | 0.03     | -        | 0.23       |
| Milford                   | 1,673      | 0.10         | -        | -        | 0.10       |
| Minersville               | 593        | 0.20         | -        | -        | 0.20       |
| Modena                    | 160        | 0.50         | 0.04     | -        | 0.54       |
| Mount Carmel              | 125        | 0.85         | 0.09     | -        | 0.94       |
| Mount Carmel Junction     | 10         | (0.80)       | 0.05     | -        | 0.85       |
| New Castle                | 115        | 0.60         | 0.05     | -        | 0.65       |
| New Harmony               | 126        | 1.20         | 0.68     | -        | 1.88       |
| Orderville                | 371        | 1.50         | 0.10     | -        | 1.60       |
| Painte Indian Reservation | 95         | (0.30)       | -        | -        | 0.30       |
| Panguitch                 | 1,500      | 0.20         | 0.50     | -        | 0.70       |
| Paragonah                 | 404        | 0.40         | 0.02     | -        | 0.42       |
| Parowan                   | 1,455      | 0.40         | 0.02     | -        | 0.42       |
| Pintura                   | 50         | 1.20         | 1.00     | -        | 2.20       |
| Rockville                 | 125        | 3.00         | 0.10     | -        | 3.10       |
| Saint George              | 5,000      | 3.00         | 0.70     | -        | 3.70       |
| Santa Clara               | 319        | 3.50         | 0.77     | -        | 4.27       |
| Shivwits                  | 95         | 2.80         | 0.80     | -        | 3.60       |
| Springdale                | 209        | 2.60         | 0.09     | -        | 2.69       |
| Summit                    | 146        | (0.50)       | 0.02     | -        | 0.52       |
| Toquerville               | 219        | 2.00         | 0.33     | -        | 2.33       |
| Uvada                     | 15         | (0.70)       | -        | -        | 0.70       |
| Veyo                      | 100        | 2.00         | 0.82     | -        | 2.82       |
| Vic's Place               | 3          | (1.20)       | 0.68     | -        | 1.88       |
| Vic's Service Station     | 2          | (3.00)       | 0.90     | -        | 3.90       |
| Virgin                    | 147        | 1.50         | 0.12     | -        | 1.62       |

UTAHEstimated Radiation Doses (Roentgens)

| <u>Location</u> | <u>Population</u>      | <u>Pre-Plumbob</u> | <u>Plumbob</u> | <u>Hardtack</u> | <u>Cumulative</u> |
|-----------------|------------------------|--------------------|----------------|-----------------|-------------------|
| Washington      | 435                    | 3.00               | 0.30           | -               | 3.30              |
| Zane            | 25                     | 0.30               | -              | -               | 0.30              |
| Zion Lodge      | Variable <sup>B/</sup> | (1.00)             | 0.16           | -               | 1.16              |

Footnotes concerning populations of communities

1. Lake Mohave - also some transients.
2. Apex - about 50 day workers; generally only a watchman at night.
3. Bardoli Ranch - population only 1 after Plumbob.
4. Bonanza Boy Scout Camp - variable population, summer months only.
5. Railroad maintenance stations (Boyd, Cloud, Etna, Galt, Garnet, Hoya, Kyle, Leith, Rox, Stone, Vigo)-population variable from 0 to about 15.
6. Butler Ranch - Mrs. Butler was absent during the important fallout in Plumbob, (from the Smoky burst) and Mr. Butler was evacuated for a few hours shortly after the fallout arrived. Personnel film badges indicated that Mrs. Butler received less than 2 Roentgens and that Mr. Butler received less than 5 Roentgens.
7. Crystal - unpopulated after Plumbob.
8. Desert Rock - unpopulated except during major test series.
9. Dodge Construction Camp - unpopulated except Plumbob series.
10. Groom Mine - population variable 2-10 prior to Plumbob, intermittent during Plumbob but only trivial doses indicated by personnel film badges during Plumbob.
11. Indian Springs - population variable, about 250 plus 2400 on military post during Plumbob.
12. Lehman Caves - tourists during summer season.
13. Read - population 3 during the Teapot series only, and these were evacuated for 7-10 days during the highest fallout activity.
14. Ravella Mill - unpopulated prior to Plumbob.
15. Riverside - population 2-14 through Upshot-Knothole, 2 during Teapot and 0 after Teapot.
16. Warm Springs Ranch - up to 500 people on weekends during the summer.
17. Watertown - population 0 prior to Plumbob; about 300 during first month of Plumbob, and 2 thereafter.
18. Bryce Canyon and Zion Lodge - many tourists during summer.

TABLE IIComparison of Film Badge Readings

| <u>Ratio</u><br><u>Persons/Area</u> | <u>Percentage of total</u><br><u>Number of Badges</u> |
|-------------------------------------|-------------------------------------------------------|
|-------------------------------------|-------------------------------------------------------|

Film badge readings on persons

not distinguishable above background 6.

&gt; 0 &lt; .2 6.

0.2 - 0.4 13.

0.4 - 0.6 26.

0.6 - 0.8 13.

0.8 - 1.0 6.

1.0 - 1.2 13.

1.2 - 1.4 6.

1.4 - 1.6 1.

1.6 - 1.8 1.

1.8 - 2.0 1.

&gt; 2.0 5.

Area film badge readings

not distinguishable above background 3.

\* Tabulated by Dr. A. Vay Shelton, Chairman, Lawrence Radiation Laboratory, University of California

TABLE III

| Ranking                               | Shielding Factor | Range of Shielding Factors |
|---------------------------------------|------------------|----------------------------|
| 1. Heavy Construction                 | 4.60             | 2.27 - 8.50                |
| 2. Large Light Storage Type Buildings | 2.87             | 2.45 - 3.66                |
| 3. Light Construction Domicile Types  | 2.36             | 1.26 - 4.11                |
| 4. Vehicles (Pickup Trucks)           | 2.21             | 1.45 - 4.5                 |
| 5. Trailer Type Domiciles             | 1.56             | 1.22 - 1.82                |

TABLE IV  
MILK SAMPLES

PRE- AND POST-FLYINGBOM SERIES SR90 AND CS137 CONTENT IN MILK

| Location         | Date Sampled | Type and Origin of Feed as Indicated by Owner of Herd | SR90 $\mu\text{Ci/g Cs}$ | CS137 $\text{d/m/quart}$ |
|------------------|--------------|-------------------------------------------------------|--------------------------|--------------------------|
| Alamo, Nevada    | 5/2/57       | Idaho hay, St. George concentrate                     | 17.4                     | 27                       |
| " "              | 8/3/57       | No information available                              | 5.3                      | 75                       |
| " "              | 10/31/57     | Alfalfa pasture, St. George concentrate               | 5.0                      | 44                       |
| Antimony, Utah   | 9/20/57      | No information available                              | 13.6                     | 119                      |
| " "              | 10/21        | Dry feeding exclusively                               | 10.0                     | 121                      |
| Bishop, Calif.   | 11/6/57      | Hay from local source                                 | 3.2                      | 32                       |
| Fremont, Utah    | 9/9/57       | Hay 20 %, pasture 80 %, commercial feed               | 12.1                     | 99                       |
| " "              | 9/21/57      | No information                                        | 9.3                      | 83                       |
| " "              | 10/19/57     | Alfalfa pasture, commercial feed                      | 4.9                      | 56                       |
| Lund, Nevada     | 11/4/57      | 1957 hay, alfalfa pasture, local grain                | 3.2                      | 71                       |
| Mequite, Nevada  | 8/2/57       | No information available                              | -                        | 70                       |
| " "              | 10/23/57     | Local hay, St. George feed                            | 6.1                      | 58                       |
| Milford, Utah    | 4/29/57      | 1956 hay, home grown grain                            | 3.1                      | 63                       |
| " "              | 10/26/57     | 50 % pasture, 50 % 1957 hay, grain                    | 2.7                      | 29                       |
| Pahrump, Nevada  | 11/1/57      | Home grown hay, ensilage, grain                       | 6.0                      | 31                       |
| Panguitch, Utah  | 9/8/57       | Local pasture                                         | 37.3                     | 159                      |
| " "              | 9/20/57      | Local pasture                                         | 17.0                     | 94                       |
| " "              | 10/21/57     | Old hay                                               | 26.2                     | 182                      |
| St. George, Utah | 8/31/57      | 1957 hay, third cutting, grain                        | 2.6                      | 45                       |
| " "              | 10/28/57     | 1957 hay and ensilage, grain                          | 4.6                      | 103                      |
| Vero, Utah       | 7/9/57       | Hay from Enterprise, local pasture                    | 7.2                      | 69                       |
| " "              | 7/15         | No record taken                                       | 8.2                      | 52                       |
| " "              | 8/3/57       | No record taken                                       | 5.1                      | 65                       |
| " "              | 9/10/57      | Hay from Enterprise and local pasture                 | 4.1                      | 38                       |
| " "              | 10/27/57     | Hay from 1957 cutting                                 | 4.0                      | 45                       |

TABLE V

## MILK SAMPLES

| Sample                           | Date of Collection | Ash (gm/l) | Gross Activity ( $\mu$ c/g ash) | Ca (gm/l) | $^{131}\text{I}$ † | Total Sr       | Sr ( $\mu$ c/l) | Ba $^{140}\text{m}$ | Cs $^{137}$    |
|----------------------------------|--------------------|------------|---------------------------------|-----------|--------------------|----------------|-----------------|---------------------|----------------|
| Glendale, Nevada area            | 6-20-58            |            |                                 | 1.086     | 0                  | 14.1 $\pm$ 1.3 | 4.5 $\pm$ 0.7   | 3.1 $\pm$ 1.4       | 45.0 $\pm$ 1.6 |
|                                  | 7-16-58            | 7.27       | 209.1 $\pm$ 5.1                 | 1.070     | 84                 | 17.9 $\pm$ 1.4 | 3.5 $\pm$ 0.6   | 9.8 $\pm$ 1.6       | 46.5 $\pm$ 1.7 |
|                                  | 8-26-48            | 7.26       | 181.5 $\pm$ 3.0                 | 1.226     | 16.3**             | 16.9 $\pm$ 1.5 | 2.0 $\pm$ 0.6   | 0.7 $\pm$ 0.7       | 44.2 $\pm$ 1.8 |
|                                  | 9-17-58            | 7.33       | 192.4 $\pm$ 5.0                 | 1.097     | 18                 | 26.6 $\pm$ 1.6 | 3.5 $\pm$ 0.5   | 5.0 $\pm$ 1.6       | 47.1 $\pm$ 1.8 |
|                                  | 10-28-58           | 7.55       | 196.5 $\pm$ 5.1                 | 1.056     | 293**              | 24.8 $\pm$ 1.7 | 1.8 $\pm$ 0.3   | 16.2 $\pm$ 1.0**    | 24.7 $\pm$ 1.2 |
|                                  | 11-26-58           | 7.75       | 182.9 $\pm$ 5.0                 | 1.145     | 49**               | 40.9 $\pm$ 1.9 | 3.2 $\pm$ 0.7   | 3.6 $\pm$ 0.8**     | 43.7 $\pm$ 1.3 |
|                                  | 12-28-58           | 7.43       | 187.4 $\pm$ 4.5                 | 1.157     | 27**†              | 9.9 $\pm$ 1.9  | 2.9 $\pm$ 0.7   | 0*                  | 26.1 $\pm$ 1.2 |
|                                  | 1-26-59            | 7.57       | 191.4 $\pm$ 4.8                 | 1.172     | 0                  | 5.4 $\pm$ 1.4  | 5.0 $\pm$ 0.7   | 0                   | 32.1 $\pm$ 1.3 |
|                                  | 2-18-59            | 7.50       | 189.8 $\pm$ 7.8                 | 1.154     | 3                  | 5.4 $\pm$ 1.2  | 3.1 $\pm$ 0.5   | 2.1 $\pm$ 1.6       | 25.8 $\pm$ 1.1 |
| St. George-Cedar City area, Utah | 6-21-58            |            |                                 | 1.072     | 0                  | 17.1 $\pm$ 1.4 | 3.5 $\pm$ 0.7   | 3.4 $\pm$ 1.4       | 45.1 $\pm$ 1.6 |
|                                  | 7-11-58            | 7.26       | 197.6 $\pm$ 5.1                 | 1.040     | 43                 | 10.6 $\pm$ 1.3 | 3.2 $\pm$ 0.6   | 5.4 $\pm$ 1.2       | 35.7 $\pm$ 1.5 |
|                                  | 8-16-58            | 8.44       | 171.5 $\pm$ 4.9                 | 1.086     | 25.8               | 23.6 $\pm$ 1.4 | 2.3 $\pm$ 0.7   | 3.6 $\pm$ 1.4       | 32.7 $\pm$ 1.7 |
|                                  | 10-15-58           | 7.47       | 204.7 $\pm$ 5.0                 | 1.074     | 0.0                | 30.7 $\pm$ 1.9 | 2.6 $\pm$ 0.7   | 0.0                 | 32.4 $\pm$ 1.3 |
|                                  | 11-14-58           | 7.99       | 172.1 $\pm$ 5.0                 | 1.121     | 0                  | 30.8 $\pm$ 2.1 | 4.1 $\pm$ 1.0   | 1.8 $\pm$ 2.0       | 32.0 $\pm$ 1.3 |
|                                  | 1-13-59            | 7.59       | 185.9 $\pm$ 5.4                 | 1.135     | 0                  | 9.9 $\pm$ 1.3  | 3.5 $\pm$ 0.5   | 0                   | 24.4 $\pm$ 1.3 |
|                                  | 2-10-59            | 7.62       | 195. $\pm$ 5.3                  | 1.154     | 3                  | 5.9 $\pm$ 1.2  | 4.1 $\pm$ 0.5   | 0                   | 29.1 $\pm$ 1.2 |

\* Corrected for decay to time of collection  
 \*\* Uncorrected for decay to time of collection  
 †  $^{131}\text{I}$  values had an error of  $\pm 20 \mu\text{c/l}$  when analyzed

TABLE VI

## Soils \*

| Location            | Strontium-90<br>(millicuries per square mile) |
|---------------------|-----------------------------------------------|
| Tempiute, Nevada    | 42.3                                          |
| Cedar City, Utah    | 36.7                                          |
| Lund, Nevada        | 30.7                                          |
| Beaver, Utah        | 29.6                                          |
| Eureka, Nevada      | 25.6                                          |
| St. George, Utah    | 24.1                                          |
| Alamo, Nevada       | 15.3                                          |
| Bishop, California  | 14.9                                          |
| Caliente, Nevada    | 14.6                                          |
| Overton, Nevada     | 9.7                                           |
| Mesquite, Nevada    | 5.2                                           |
| Barstow, California | 1.96                                          |

\* Samples collected by Mr. Kermit Larson of UCLA, prepared for analyses by Dr. Lyle Alexander of the U. S. Department of Agriculture and analyzed by the Health and Safety Laboratory of the Atomic Energy Commission.



TABLE VII  
Results of Sr<sup>90</sup> Analyses

Minnesota Wheat

As Reported January 25, 1959

| <u>Sample No.</u> | <u>Location</u>    | <u>Varieties (Spring Wheat)</u>                       | <u>Year</u> | <u>% ash of<br/>wt. rec'd</u> | <u>d/m Sr<sup>90</sup><br/>per g ash</u> | <u>% Ca<br/>in ash</u> | <u>μc Sr<sup>90</sup>/<br/>g. Ca</u> | <u>μc Sr<sup>90</sup> / whole<br/>/kgm. wheat</u> |
|-------------------|--------------------|-------------------------------------------------------|-------------|-------------------------------|------------------------------------------|------------------------|--------------------------------------|---------------------------------------------------|
| 1                 | Rosemount          | Henry, Selkirk, Mids, Rushmore,<br>Lee, Thatcher      | 1956        | 1.93                          | 8.83 ± 0.35                              | 2.44                   | 163 ± 7                              | 77                                                |
| 2                 | Southwest          | Lee, Mids, Thatcher, Henry<br>Selkirk, Rushmore       | 1956        | 2.07                          | 7.06 ± 0.34<br>8.20 ± 0.47               | 2.02<br>2.04           | 157 ± 7<br>181 ± 10                  | 67<br>77                                          |
| 3                 | Grand Rapids       | Lee, Mids, Thatcher, Henry,<br>Selkirk, Rushmore      | 1956        | 2.21                          | 3.66 ± 0.28                              | 1.87                   | 88.2 ± 7.0                           | 37                                                |
| 4                 | Morris             | Lee, Mids, Rushmore, Thatcher,<br>Selkirk, Henry      | 1956        | 2.00                          | 3.09 ± 0.27                              | 1.70                   | 81.8 ± 7.1                           | 28                                                |
| 5                 | Duluth             | Lee, Henry, Mids, Rushmore,<br>Selkirk, Conley        | 1956        | 2.27                          | 3.74 ± 0.28                              | 2.04                   | 92.4 ± 6.4                           | 38                                                |
| 6                 | Crookston          | Henry, Rushmore, Lee, Mids,<br>Thatcher               | 1956        | 1.55                          | 2.33 ± 0.33<br>2.42 ± 0.29               | 1.47<br>1.42           | 71.4 ± 10.2<br>76.8 ± 9.2            | 16<br>17                                          |
| 7                 | Waseca             | Mids, Lee, Rushmore, Thatcher,<br>Selkirk, Henry      | 1956        | 2.07                          | 4.91 ± 0.38                              | 2.36                   | 93.6 ± 7.2                           | 46                                                |
| 8                 | North<br>Minnesota | Lee, Selkirk, Henry, Russell,<br>(Lee x Kenya Farmer) | 1957        | 1.91                          | 5.43 ± 0.29                              | 1.98                   | 124 ± 7                              | 47                                                |
| 9                 | Rosemount          | Selkirk, Lee, Thatcher                                | 1957        | 2.26                          | 6.36 ± 0.42                              | 1.91                   | 150 ± 10                             | 65                                                |
| 10                | Morris             | Thatcher                                              | 1957        | 2.21                          | 8.11 ± 0.36<br>7.85 ± 0.49               | 1.88<br>1.73           | 194 ± 8<br>205 ± 13                  | 81<br>78                                          |
| 11                | Grand Rapids       | Lee, Selkirk, Russell (Lee x<br>Kenya Farmer)         | 1957        | 2.06                          | 6.54 ± 0.42                              | 1.58                   | 187 ± 12                             | 61                                                |
| 12                | Crookston          | Thatcher, Lee, Selkirk, Conley                        | 1957        | 3.64                          | 6.78 ± 0.42<br>6.95 ± 0.33               | 0.50<br>0.52           | 610 ± 38<br>602 ± 29                 | 111<br>114                                        |

Results of Sr<sup>90</sup> Analyses - Continued

Minnesota Wheat

As Reported January 25, 1959

| <u>Sample No.</u> | <u>Location</u>        | <u>Varieties (Spring Wheat)</u>                          | <u>Year</u> | <u>% ash of<br/>wt. rec'd</u> | <u>d/m Sr<sup>90</sup><br/>per g. ash</u> | <u>% Ca<br/>in ash</u> | <u>μc Sr<sup>90</sup> /<br/>g. Ca</u> | <u>μc Sr<sup>90</sup> / whole<br/>/kgm. wheat</u> |
|-------------------|------------------------|----------------------------------------------------------|-------------|-------------------------------|-------------------------------------------|------------------------|---------------------------------------|---------------------------------------------------|
| 13                | Southwest              | Thatcher, Selkirk, Lee,<br>(Lee x Kenya Farmer), Russell | 1957        | 2.12                          | 5.38 ± 0.31                               | 1.66                   | 146 ± 8                               | 51                                                |
| 14                | Waseca                 | Thatcher, Selkirk, Conley<br>(Lee x Kenya Farmer)        | 1957        | 2.15                          | 4.80 ± 0.37                               | 2.06                   | 105 ± 8                               | 47                                                |
| 15                | Duluth                 | Selkirk, Russell                                         | 1958        | 1.84                          | 4.28 ± 0.31<br>4.09 ± 0.28                | 1.60<br>1.82           | 121 ± 9<br>101 ± 7                    | 36<br>34                                          |
| 16                | Grand Rapids           | Varieties not known                                      | 1958        | 1.77                          | 7.52 ± 0.35                               | 1.84                   | 184 ± 9                               | 60                                                |
| 17                | Rosemount              | Selkirk, Conley                                          | 1958        | 1.35                          | 5.88 ± 0.32                               | 2.13                   | 124 ± 7                               | 36                                                |
| 18                | Unknown                | Russell, MO58                                            | 1958        | 1.70                          | 6.99 ± 0.32                               | 1.86                   | 169 ± 8                               | 54                                                |
| 19                | Southwest              | Conley, Selkirk                                          | 1958        | 1.84                          | 4.48 ± 0.29                               | 1.06                   | 191 ± 12                              | 37                                                |
| 20                | Unknown                | Conley, UF58                                             | 1958        | 2.05                          | 5.78 ± 0.34                               | 1.65                   | 158 ± 9                               | 53                                                |
| 21                | Waseca                 | Selkirk                                                  | 1958        | 1.84                          | 4.89 ± 0.32                               | 1.70                   | 129 ± 8                               | 41                                                |
| 22                | Crookston              | Conley                                                   | 1958        | 2.00                          | 4.58 ± 0.29<br>4.84 ± 0.31                | 0.97<br>1.02           | 212 ± 13<br>214 ± 14                  | 41<br>43                                          |
| 23                | International<br>Falls | Unknown                                                  | 1958        | 1.98                          | 4.59 ± 0.30<br>4.78 ± 0.31                | 1.73<br>1.76           | 120 ± 8<br>122 ± 8                    | 41<br>43                                          |

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REPORT OF THE  
DEPARTMENT AND LABORATORIES OF NUCLEAR MEDICINE  
AND RADIATION BIOLOGY  
UNIVERSITY OF CALIFORNIA AT LOS ANGELES

|           | <u>24 HR. AIR SAMPLE (a)</u> |                          | <u>GUM PAPER</u>          |
|-----------|------------------------------|--------------------------|---------------------------|
| June 1958 | Beta                         | Beta                     | Beta                      |
| Date      | $\mu\text{c}/\text{M}^3$     | $\mu\text{c}/\text{M}^3$ | $\mu\text{c}/\text{ft}^2$ |
|           | <u>4 Hr ct</u>               | <u>4 Day ct</u>          | <u>Per 24 hr Exp.</u>     |
| 1         | 7.0                          | 3.3                      | 58                        |
| 2         | 4.6                          | 2.3                      | 65                        |
| 3         | 5.2                          | 2.4                      | 78                        |
| 4         | 6.6                          | 2.6                      | 13                        |
| 5         | 3.6                          | 1.9                      | 23                        |
| 6         | 5.0                          | 2.4                      | 120                       |
| 7         | 6.3                          | 2.7                      | 36                        |
| 8         | 5.2                          | 1.9                      | 46                        |
| 9         | 4.8                          | 1.0                      | 29                        |
| 10        | 5.2                          | 1.6                      | 23                        |
| 11        | 5.0                          | 1.7                      | 53                        |
| 12        | 3.2                          | 1.6                      | 19                        |
| 13        | 3.5                          | 1.9                      | 46                        |
| 14        | 6.0                          | 2.2                      | 1.8                       |
| 15        | 5.3                          | 1.8                      | 52                        |
| 16        | 3.5                          | 2.0                      | 40                        |
| 17        | 6.0                          | 2.0                      | 6.4                       |
| 18        | 7.5                          | 3.2                      | 16                        |
| 19        | 6.4                          | 3.5                      | 36                        |
| 20        | 8.8                          | 2.2                      | 17                        |
| 21        | 7.5                          | 2.5                      | 32                        |
| 22        | 6.5                          | 2.9                      | 28                        |
| 23        | 8.6                          | 2.7                      | 64                        |
| 24        | 6.5                          | 2.2                      | 17                        |
| 25        | 6.2                          | 2.0                      | 26                        |
| 26        | 5.2                          | 2.4                      | 35                        |
| 27        | 8.9                          | 3.1                      | 14                        |
| 28        | 6.5                          | 2.7                      | 40                        |
| 29        | 7.3                          | 3.1                      | 69                        |
| 30        | 6.1                          | 2.7                      | 39                        |

NOTES:

- (1) No rain during month of June 1958.
- (2) Gamma Background readings for June at 3 ft. above ground averaged 0.009 mr/hr. with no reading higher than 0.013 mr/hr.
- (a) Air sample collected for 24 hours followed by a four hour then a four day lapse until counting time.

| July<br>1958<br>Date | 24 HR. AIR SAMPLE                           |                                              | GUM PAPER                                           |
|----------------------|---------------------------------------------|----------------------------------------------|-----------------------------------------------------|
|                      | Beta<br>$\mu\text{c}/\text{M}^3$<br>4 hr ct | Beta<br>$\mu\text{c}/\text{M}^3$<br>4 Day ct | Beta<br>$\mu\text{c}/\text{ft}^2$<br>Per 24 hr Exp. |
| 1                    | 7.9                                         | 2.3                                          | 18.0                                                |
| 2                    | 6.4                                         | 2.8                                          | 34                                                  |
| 3                    | 5.9                                         | 3.1                                          | 28                                                  |
| 4                    | 7.3                                         | 3.9                                          | 28                                                  |
| 5                    | 6.4                                         | 3.9                                          | 19                                                  |
| 6                    | 7.0                                         | 2.6                                          | 26                                                  |
| 7                    | 6.8                                         | 2.7                                          | 61                                                  |
| 8                    | 6.4                                         | 1.8                                          | 22                                                  |
| 9                    | 7.4                                         | 2.3                                          | 27                                                  |
| 10                   | 6.5                                         | 2.5                                          | 26                                                  |
| 11                   | 6.7                                         | 2.9                                          | 50                                                  |
| 12                   | 6.3                                         | 1.6                                          | 41                                                  |
| 13                   | 6.5                                         | 3.2                                          | 32                                                  |
| 14                   | 7.3                                         | 2.2                                          | 41                                                  |
| 15                   | 6.1                                         | 2.4                                          | 26                                                  |
| 16                   | 5.9                                         | 2.1                                          | 24                                                  |
| 17                   | 6.8                                         | 1.4                                          | 10                                                  |
| 18                   | 6.1                                         | 2.2                                          | 35                                                  |
| 19                   | 5.1                                         | 1.3                                          | 23                                                  |
| 20                   | 5.4                                         | 2.0                                          | 27                                                  |
| 21                   | 4.7                                         | 1.5                                          | 36                                                  |
| 22                   | 5.7                                         | 1.4                                          | 10                                                  |
| 23                   | 4.7                                         | 1.5                                          | 10                                                  |
| 24                   | 4.2                                         | 1.2                                          | 8                                                   |
| 25                   | 5.6                                         | 1.4                                          | 28                                                  |
| 26                   | 3.8                                         | 1.5                                          | 26                                                  |
| 27                   | 4.4                                         | 0.5                                          | 11                                                  |
| 28                   | 4.1                                         | 1.5                                          | 41                                                  |
| 29                   | 6.8                                         | 2.3                                          | 38                                                  |
| 30                   | 8.6                                         | 4.5                                          | 34                                                  |
| 31                   | 5.7                                         | 3.0                                          | 50                                                  |

NOTES: No rain during month of July, 1958.

Gamma background readings for July at 3 ft. above ground averaged 0.006 mr/hr with no reading higher than 0.010 mr/hr.

- 2 -

| Aug.<br>1958<br>Date | 24 HR. AIR SAMPLE                           |                                              | GUM PAPER                                           |
|----------------------|---------------------------------------------|----------------------------------------------|-----------------------------------------------------|
|                      | Beta<br>$\mu\text{c}/\text{M}^3$<br>4 hr ct | Beta<br>$\mu\text{c}/\text{M}^3$<br>4 Day ct | Beta<br>$\mu\text{c}/\text{ft}^2$<br>Per 24 hr Exp. |
| 1                    | 4.6                                         | 2.9                                          | 50                                                  |
| 2                    | 7.7                                         | 3.3                                          | 20                                                  |
| 3                    | 9.6                                         | 3.1                                          | 77                                                  |
| 4                    | 5.0                                         | 2.2                                          | 2.0                                                 |
| 5                    | 3.5                                         | 1.8                                          | 37                                                  |
| 6                    | 3.5                                         | 1.6                                          | 55                                                  |
| 7                    | 3.9                                         | 2.1                                          | 5.9                                                 |
| 8                    | 5.0                                         | 2.8                                          | 35                                                  |
| 9                    | 6.8                                         | 3.2                                          | 50                                                  |
| 10                   | 5.5                                         | 2.9                                          | 14                                                  |
| 11                   | 6.4                                         | 2.9                                          | 5.9                                                 |
| 12                   | 5.9                                         | 1.6                                          | 7.3                                                 |
| 13                   | 5.5                                         | 2.6                                          | 220*                                                |
| 14                   | 7.7                                         | 3.6                                          | 200*                                                |
| 15                   | 6.4                                         | 2.6                                          | 14                                                  |
| 16                   | 6.8                                         | 3.2                                          | 160*                                                |
| 17                   | 5.5                                         | 2.4                                          | 27                                                  |
| 18                   | 5.5                                         | 1.7                                          | 5.0                                                 |
| 19                   | 5.9                                         | 1.9                                          | 37                                                  |
| 20                   | 3.0                                         | 1.2                                          | 40                                                  |
| 21                   | 2.8                                         | 1.3                                          | 21                                                  |
| 22                   | 4.5                                         | 2.0                                          | 23                                                  |
| 23                   | 4.4                                         | 2.1                                          | 44                                                  |
| 24                   | 5.0                                         | 2.4                                          | 21                                                  |
| 25                   | 5.0                                         | 1.8                                          | 43                                                  |
| 26                   | 5.0                                         | 1.8                                          | 11                                                  |
| 27                   | 3.3                                         | 1.7                                          | 10                                                  |
| 28                   | 3.5                                         | 1.8                                          | 26                                                  |
| 29                   | 5.0                                         | 2.2                                          | 40                                                  |
| 30                   | 6.5                                         | 2.9                                          | 5.5                                                 |
| 31                   | 5.9                                         | 2.6                                          | 14                                                  |

NOTES:

- (1) \*Trace rains on the 13th and 15th affected the gum papers removed for analysis on the 13th, 14th and 16th of this month.
- (2) There was no measurable volume of rain during August 1958.
- (3) Gamma Background readings for August 1958 at 3 ft. above the ground averaged 0.007 mr/hr. with no reading higher than 0.012 mr/hr.

- 3 -

| Sept.<br>1958<br>Date | 24 HR. AIR SAMPLE                            |                                               | GUM PAPER                                            |
|-----------------------|----------------------------------------------|-----------------------------------------------|------------------------------------------------------|
|                       | Beta<br>$\mu\text{mc}/\text{M}^3$<br>4 hr ct | Beta<br>$\mu\text{mc}/\text{M}^3$<br>4 Day ct | Beta<br>$\mu\text{mc}/\text{ft}^2$<br>Per 24 hr Exp. |
| 1                     | 4.5                                          | 1.3                                           | 44.0                                                 |
| 2                     | 4.2                                          | 2.1                                           | 17.0                                                 |
| 3                     | 3.5                                          | 2.2                                           | 33                                                   |
| 4                     | 3.7                                          | 1.4                                           | 67                                                   |
| 5                     | 5.5                                          | 1.6                                           | 0.0                                                  |
| 6                     | 4.4                                          | 2.1                                           | 9.2                                                  |
| 7                     | 4.6                                          | 2.5                                           | 7.3                                                  |
| 8                     | 8.6                                          | 1.7                                           | 57.0                                                 |
| 9                     | 7.7                                          | 2.4                                           | 2.9                                                  |
| 10                    | 6.9                                          | 1.9                                           | 46.                                                  |
| 11                    | 4.3                                          | 1.4                                           | 19.                                                  |
| 12                    | 4.6                                          | 1.2                                           | 1.8                                                  |
| 13                    | 4.7                                          | 1.8                                           | 17.                                                  |
| 14                    | 4.8                                          | 2.3                                           | 27.                                                  |
| 15                    | 4.7                                          | 1.9                                           | 8.2                                                  |
| 16                    | 8.0                                          | 3.0                                           | 17.                                                  |
| 17                    | 9.1                                          | 3.1                                           | 30.                                                  |
| 18                    | 7.4                                          | 2.4                                           | 5.5                                                  |
| 19                    | 8.8                                          | 3.0                                           | 19.                                                  |
| 20                    | 5.9                                          | 2.3                                           | 8.4                                                  |
| 21                    | 5.3                                          | 1.6                                           | 31.                                                  |
| 22                    | 3.7                                          | 1.1                                           | 14.                                                  |
| 23                    | 3.5                                          | 2.6                                           | 130.*                                                |
| 24                    | 4.4                                          | 2.2                                           | 140.*                                                |
| 25                    | 6.1                                          | 2.4                                           | 18.                                                  |
| 26                    | 8.8                                          | 2.5                                           | 24.                                                  |
| 27                    | 7.0                                          | 2.2                                           | 19.                                                  |
| 28                    | 8.2                                          | 2.3                                           | 39.                                                  |
| 29                    | 6.5                                          | 2.2                                           | 24.                                                  |
| 30                    | 6.1                                          | 1.7                                           | 39.                                                  |

## NOTES:

- (1) \*Two slight rains on the 23rd of September affected the gum papers removed for analysis on the 23rd and 24th. Total volume collected for the morning rain was 1.2 ml which indicated 40  $\mu\text{mc}/\text{ml}$  beta activity and 0.13  $\mu\text{mc}/\text{ml}$  alpha activity. The afternoon rain volume collected was 2.0 ml which indicated 7.5  $\mu\text{mc}/\text{ml}$  beta activity and 0.01  $\mu\text{mc}/\text{ml}$  alpha activity. Alpha counts on these samples were made after natural radon-thoron products had decayed.
- (2) Gamma Background readings for September 1958 at 3 ft. above the ground averaged 0.007 mr/hr. with no reading higher than 0.013 mr/hr.

| Oct.<br>1958<br>Date | 24 HR. AIR SAMPLE                            |                                               | GUM PAPER                                            |
|----------------------|----------------------------------------------|-----------------------------------------------|------------------------------------------------------|
|                      | Beta<br>$\mu\text{mc}/\text{M}^3$<br>4 hr ct | Beta<br>$\mu\text{mc}/\text{M}^3$<br>4 Day ct | Beta<br>$\mu\text{mc}/\text{ft}^2$<br>Per 24 hr Exp. |
| 1                    | 5.3                                          | 1.7                                           | 47                                                   |
| 2                    | 6.5                                          | 1.7                                           | 24                                                   |
| 3                    | 6.6                                          | 2.3                                           | 16                                                   |
| 4                    | 6.1                                          | 1.7                                           | 11                                                   |
| 5                    | 6.4                                          | 3.5                                           | 33                                                   |
| 6                    | 6.6                                          | 2.2                                           | 14                                                   |
| 7                    | 8.4                                          | 2.7                                           | 22                                                   |
| 8                    | 7.0                                          | 2.6                                           | 25                                                   |
| 9                    | 5.7                                          | 2.0                                           | 11                                                   |
| 10                   | 5.4                                          | 2.4                                           | 19                                                   |
| 11                   | 5.8                                          | 2.0                                           | 22                                                   |
| 12                   | 4.0                                          | 1.2                                           | 11                                                   |
| 13                   | 6.4                                          | 1.3                                           | 14                                                   |
| 14                   | 8.8                                          | 2.2                                           | 31                                                   |
| 15                   | 7.2                                          | 2.0                                           | 33                                                   |
| 16                   | 7.4                                          | 2.2                                           | 26                                                   |
| 17                   | 7.8                                          | 2.3                                           | 100                                                  |
| 18                   | 9.8                                          | 3.4                                           | 18                                                   |
| 19                   | 8.0                                          | 2.5                                           | 14                                                   |
| 20                   | 7.7                                          | 2.8                                           | 60                                                   |
| 21                   | 17.                                          | 9.2                                           | 19                                                   |
| 22                   | 40.                                          | 33.                                           | 22                                                   |
| 23                   | 50.                                          | 37.                                           | 150                                                  |
| 24                   | 44.                                          | 32.                                           | 1210*                                                |
| 25                   | 26.                                          | 18.                                           | 1770*                                                |
| 26                   | 17.                                          | 10.                                           | 110                                                  |
| 27                   | 13.                                          | 5.6                                           | 86                                                   |
| 28                   | 30.                                          | 19.                                           | 6660                                                 |
| 29                   | 87.                                          | 35.                                           | 210                                                  |
| 30                   | 700.                                         | 145.                                          | 3400                                                 |
| 31                   | 163.                                         | 72.                                           | 1600                                                 |

## NOTE:

- (1) \* Trace rains on 24th and 25th effected the gum papers removed for analysis on 24th and 25th of October, 1958.
- (2) There was no measurable volume of rain during October, 1958.
- (3) Gamma background readings for October, 1958 at 3 ft above the ground averaged 0.007 mr/hr. There was one significant increase recorded on Oct. 29, 1958 at 4:20 PM the background record started to increase until 5:30 PM when a maximum reading of 0.017 mr/hr was recorded. The background remained at this level almost 2 hours and then dropped to an average of .013 mr/hr until 8:30 AM on Oct. 30, 1958. At 8:45 AM on Oct. 30 the level dropped to .008 mr/hr and during the remainder of that day and the following day the average background level was 0.007 mr/hr.

| Nov.<br>1958<br>Date | 24 HR. AIR SAMPLE                           |                                              | GUM PAPER                                           |
|----------------------|---------------------------------------------|----------------------------------------------|-----------------------------------------------------|
|                      | Beta<br>$\mu\text{c}/\text{M}^3$<br>4 hr ct | Beta<br>$\mu\text{c}/\text{M}^3$<br>4 Day ct | Beta<br>$\mu\text{c}/\text{ft}^2$<br>Per 24 hr Exp. |
| 1                    | 38                                          | 23                                           | 1100                                                |
| 2                    | 180                                         | 90                                           | 1500                                                |
| 3                    | 370                                         | 160                                          | 1000                                                |
| 4                    | 260                                         | 130                                          | 680                                                 |
| 5                    | 190                                         | 120                                          | 410                                                 |
| 6                    | 130                                         | 84                                           | 240                                                 |
| 7                    | 72                                          | 47                                           | 140                                                 |
| 8                    | 70                                          | 43                                           | 130                                                 |
| 9                    | 41                                          | 25                                           | 140                                                 |
| 10                   | 29                                          | 20                                           | 40                                                  |
| 11                   | 16                                          | 10                                           | 5000*                                               |
| 12                   | 26                                          | 19                                           | 680                                                 |
| 13                   | 16                                          | 13                                           | 60                                                  |
| 14                   | 25                                          | 14                                           | 100                                                 |
| 15                   | 13                                          | 10                                           | 210                                                 |
| 16                   | 17                                          | 13                                           | 220                                                 |
| 17                   | 13                                          | 9.2                                          | 170                                                 |
| 18                   | 12                                          | 9.8                                          | 36                                                  |
| 19                   | 25                                          | 19                                           | 39                                                  |
| 20                   | 17                                          | 14                                           | 66                                                  |
| 21                   | 19                                          | 17                                           | 170                                                 |
| 22                   | 21                                          | 14                                           | 98                                                  |
| 23                   | 20                                          | 15                                           | 78                                                  |
| 24                   | 21                                          | 7.6                                          | 48                                                  |
| 25                   | 27                                          | 8.6                                          | 50                                                  |
| 26                   | 11                                          | 7.2                                          | 98                                                  |
| 27                   | 23                                          | 8.4                                          | 19                                                  |
| 28                   | 17                                          | 10                                           | 31                                                  |
| 29                   | 26                                          | 23                                           | 22                                                  |
| 30                   | 30                                          | 28                                           | 34                                                  |

NOTES: (1) \*A rainout during the early hours of Nov. 11 affected the gum paper removed on the 11th. Total volume of rain collected was 17 ml which indicated 19  $\mu\text{c}/\text{ml}$  beta activity, and the alpha count was 0.09  $\mu\text{c}/\text{ml}$ . The rainout was 2.9  $\mu\text{c}/\text{cm}^2$  for beta and 0.014  $\mu\text{c}/\text{cm}^2$  for the alpha activity. Alpha counts on this sample were made after natural radon-thoron products had decayed.

(2) Gamma background readings for the first half of November, 1958 at 3 ft. above the ground averaged 0.007 mr/hr with no reading higher than 0.012 mr/hr.

REPORT OF THE  
DEPARTMENT AND LABORATORIES OF NUCLEAR MEDICINE  
AND RADIATION BIOLOGY  
UNIVERSITY OF CALIFORNIA AT LOS ANGELES

1 HOUR "GRAB" AIR SAMPLES TAKEN AT 15 CPM  
(8 CROSS ACTIVITY IN  $\mu\text{c}/\text{M}^3$ )

| DATE  | Hour Taken | Sampler | Int-<br>Off<br>Act-<br>ivity | (a)     |         |          |          |          |
|-------|------------|---------|------------------------------|---------|---------|----------|----------|----------|
| 10-28 | 10:30A     |         | 530                          | 267(4)  | 151(48) |          | 44(360)  | 25(840)  |
| "     | 1:00P      |         | 300                          |         | 126(45) |          |          |          |
| "     | 2:30P      |         | 300                          |         | 20(44)  |          |          |          |
| "     | 3:30P      |         | 267                          |         | 18(44)  |          |          |          |
| "     | 4:30P      |         | 360                          |         | 44(46)  |          |          |          |
| 10-29 | 9:30A      |         | 130                          | 27(2)   | 14(52)  |          |          | 3.9(916) |
| 10-29 | 2:20P      |         | 160                          |         | 23(48)  |          |          | 8.9(816) |
| "     | 3:20P      |         | 200                          |         | 31(44)  |          |          |          |
| "     | 4:40P      |         | 1300                         |         |         |          |          |          |
| 10-30 | 9:20A      |         | 2200                         | 1200(4) | 590(24) | 210(96)  | 110(223) | 81(288)  |
| "     | 10:35A     |         | 890                          | 260(4)  | 130(24) | 68(96)   |          | 79(312)  |
| "     | 11:35A     |         | 450                          | 200(4)  | 130(24) | 50(96)   |          | 31(816)  |
| "     | 12:45A     |         | 180                          | 180(4)  | 84(24)  |          |          | 10(816)  |
| "     | 1:45P      |         | 280                          |         | 41(24)  |          |          | 18(816)  |
| "     | 3:10P      |         | 180                          |         | 61(24)  |          |          |          |
| "     | 4:10P      |         | 290                          |         | 72(24)  |          |          |          |
| 10-31 | 9:35A      |         | 290                          | 78(2)   | 48(8)   |          | 27(288)  |          |
| "     | 10:38A     |         | 230                          | 49(4)   |         |          |          |          |
| "     | 11:38A     |         | 160                          | 45(4)   |         |          |          |          |
| "     | 12:38P     |         | 130                          | 55(4)   |         |          |          |          |
| "     | 1:48P      |         | 96                           | 39(2)   |         |          |          |          |
| "     | 2:48P      |         | 180                          | 47(2)   |         |          |          |          |
| "     | 3:48P      |         | 250                          | 78(2)   |         |          |          |          |
| 11-1  | 1:10P      |         |                              |         | 58(45)  |          |          |          |
| 11-3  | 10:15A     |         | 670                          | 410(4)  | 400(24) | 230(102) |          |          |
| "     | 11:15A     |         | 750                          | 437(4)  | 320(24) |          |          |          |
| "     | 12:30P     |         | 620                          | 300(4)  | 240(24) |          |          |          |
| "     | 1:45P      |         | 890                          |         | 230(24) |          |          |          |
| "     | 2:45P      |         | 630                          |         | 210(24) |          |          |          |
| "     | 3:45P      |         | 670                          |         | 260(24) |          |          |          |
| "     | 4:50P      |         | 560                          |         | 200(24) |          |          |          |
| 11-4  | 10:15A     |         | 540                          | 200(4)  | 160(24) |          |          |          |
| "     | 11:15A     |         | 700                          | 250(4)  | 190(24) |          |          |          |
| "     | 2:15P      |         | 280                          |         | 140(24) |          |          |          |
| "     | 4:30P      |         | 300                          |         |         |          |          |          |
| 11-5  | 7:30A      |         | 610                          | 130(4)  |         |          |          |          |
| 11-6  | 7:30A      |         | 410                          | 97(4)   |         |          |          |          |
| 11-7  | 7:30A      |         | 450                          | 31(24)  |         |          |          |          |
| "     |            |         | 300                          | 49(4)   | 32(28)  |          |          |          |
| "     |            |         | 230                          |         |         |          |          |          |

(a) Numbers enclosed in parenthesis represent number of hrs of decay time after sample was removed until counting time.

1 HOUR "CHAS" AIR SAMPLES TAKEN AT 15 CFM  
( $\beta$  GROSS ACTIVITY IN  $\mu\text{mc}/\text{M}^3$ )

| DATE  | Hour Taken<br>Off | Ini-<br>tial<br>Act-<br>ivity | (a)    |         |
|-------|-------------------|-------------------------------|--------|---------|
| 1958  | Sampler           |                               |        |         |
| 11-10 | 7:30A             | 53                            | 13(6)  | 3.4(24) |
| 11-12 | 7:30A             | 160                           |        | 14(24)  |
| 11-13 | 10:30A            | 220                           | 15(2)  |         |
| 11-14 | 9:25A             | 250                           | 25(2)  |         |
| 11-17 | 9:30A             | 53                            | 29(4)  | 8.9(24) |
| 11-18 | 10:30A            |                               | 120(4) | 21(24)  |
| 11-19 | 9:30A             |                               | 210(4) |         |
| 11-20 | 12:20P            |                               | 27(4)  |         |
| 11-21 | 10:30A            | 150                           |        |         |
| 11-24 | 12:00             | 110                           | 26(4)  | 11(24)  |
| 11-25 | 10:00A            | 170                           |        | 3.6(24) |
| 11-26 | 11:30A            | 151                           |        |         |

(a) Numbers enclosed in parenthesis represent number of hrs of decay time after sample was removed until counting time.

REPORT OF THE  
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UNIVERSITY OF CALIFORNIA AT LOS ANGELES

DECAY OF ROUTINE 24 HR AIR FILTER SAMPLE REMOVED

ON 10-30-58

| <u>Count Time After Collection</u> | <u>Activity <math>\mu\text{mc}/\text{M}^3</math></u> |
|------------------------------------|------------------------------------------------------|
| 2 hour                             | 710                                                  |
| 4 hour                             | 700                                                  |
| 1 day                              | 400                                                  |
| 4 day                              | 145                                                  |
| 5 day                              | 130                                                  |
| 13 day                             | 58                                                   |
| 15 day                             | 52                                                   |
| 18 day                             | 43                                                   |
| 21 day                             | 36                                                   |
| 25 day                             | 31                                                   |
| 32 day                             | 24                                                   |

**REPORT OF THE  
DEPARTMENT AND LABORATORIES OF NUCLEAR MEDICINE AND  
RADIATION BIOLOGY - UCLA**

**GAMMA BACKGROUND RECORD ON ESTERLINE ANGUS CHART  
FOR OCTOBER 1 - NOVEMBER 30, 1958**

| 1958<br>Date | Time             | Average Rdg.<br>cts/min | Equiv.<br>mr/hr |
|--------------|------------------|-------------------------|-----------------|
| 10-1         |                  | 300                     | 0.008           |
| 10-2         |                  | 250                     | 0.007           |
| 10-3         |                  | 200                     | 0.006           |
| 10-4         |                  | 250                     | 0.007           |
| 10-5         |                  | 250                     | 0.007           |
| 10-6         |                  | 250                     | 0.007           |
| 10-7         |                  | 250                     | 0.007           |
| 10-8         |                  | 250                     | 0.007           |
| 10-9         |                  | 250                     | 0.007           |
| 10-10        |                  | 250                     | 0.007           |
| 10-11        |                  | 250                     | 0.007           |
| 10-12        |                  | 300                     | 0.008           |
| 10-13        |                  | 250                     | 0.007           |
| 10-14        |                  | 200                     | 0.006           |
| 10-15        |                  | 250                     | 0.007           |
| 10-16        |                  | 250                     | 0.007           |
| 10-17        |                  | 250                     | 0.007           |
| 10-18        |                  | 250                     | 0.007           |
| 10-19        |                  | 300-350                 | 0.008-0.010     |
| 10-20        |                  | 300                     | 0.008           |
| 10-21        |                  | 300                     | 0.008           |
| 10-22        |                  | 250-300                 | 0.007-0.008     |
| 10-23        |                  | 250                     | 0.007           |
| 10-24        |                  | 250                     | 0.007           |
| 10-25        |                  | 300                     | 0.008           |
| 10-26        |                  | 250-350                 | 0.007-0.010     |
| 10-27        |                  | 250                     | 0.007           |
| 10-28        |                  | 250-300                 | 0.007-0.008     |
| 10-29        | Midnite - 9:00A  | 300                     | 0.008           |
|              | 9:00A - 4:20P    | 250                     | 0.007           |
|              | 4:20P - 5:00P    | 350                     | 0.010           |
|              | 5:00P - 5:20P    | 400                     | 0.012           |
|              | 5:20P - 7:10P    | 600                     | 0.017           |
|              | 7:10P - 7:40P    | 500                     | 0.014           |
|              | 7:40P - 9:00P    | 450                     | 0.013           |
|              | 9:00P - 11:30P   | 400                     | 0.012           |
|              | 11:30P - Midnite | 350                     | 0.010           |
| 10-30        | Midnite - 5:30A  | 350                     | 0.010           |
|              | 5:30A - 8:20A    | 450                     | 0.013           |
|              | 8:20A - 8:35A    | 550                     | 0.016           |
|              | 8:35A - 8:45A    | 400                     | 0.012           |
|              | 8:45A - 10:15A   | 350                     | 0.010           |
|              | 10:15A - 1:00P   | 300                     | 0.008           |
|              | 1:00P - 3:45P    | 250                     | 0.007           |
|              | 3:45P - 6:00P    | 250                     | 0.007           |
|              | 6:00P - Midnite  | 300                     | 0.008           |

| 1958<br>Date | Time              | Average Rdg.<br>cts/min | Equiv.<br>mr/hr |
|--------------|-------------------|-------------------------|-----------------|
| 10-31        | Midnite - 8:00A   | 300                     | 0.008           |
|              | 8:00A - 6:00P     | 250                     | 0.007           |
|              | 6:00P - Midnite   | 300                     | 0.008           |
| 11-1         | Midnite - 1:00P   | 300                     | 0.008           |
|              | 1:00P - 7:00P     | 250                     | 0.007           |
|              | 7:00P - Midnite   | 300                     | 0.008           |
| 11-2         | Midnite - 10:00A  | 300                     | 0.008           |
|              | 10:00A - 8:00P    | 250                     | 0.007           |
|              | 8:00P - Midnite   | 300                     | 0.008           |
| 11-3         | Midnite - 7:30A   | 300                     | 0.008           |
|              | 7:30A - Midnite   | 250                     | 0.007           |
| 11-4         | Midnite - Midnite | 250                     | 0.007           |
| 11-5         |                   | 250                     | 0.007           |
| 11-6         |                   | 250                     | 0.007           |
| 11-7         |                   | 250                     | 0.007           |
| 11-8         |                   | 250                     | 0.007           |
| 11-9         |                   | 250                     | 0.007           |
| 11-10        |                   | 250                     | 0.007           |
| 11-11        |                   | 250                     | 0.007           |
| 11-12        |                   | 250                     | 0.007           |
| 11-13        |                   | 250                     | 0.007           |
| 11-14        |                   | 250                     | 0.007           |
| 11-15        |                   | 250                     | 0.007           |
| 11-16        |                   | 250                     | 0.007           |
| 11-17        |                   | 250                     | 0.007           |
| 11-18        | Midnite - 2:00A   | 250                     | 0.007           |
|              | 2:00A - 5:00P     | 300                     | 0.008           |
|              | 5:00P - 5:30P     | 450                     | 0.013           |
|              | 5:30P - 10:00P    | 350                     | 0.010           |
|              | 10:00P - Midnite  | 400                     | 0.012           |
| 11-19        | Midnite - 1:30A   | 350                     | 0.010           |
|              | 1:30A - 2:50A     | 250                     | 0.007           |
|              | 2:50A - 4:20A     | 350                     | 0.010           |
|              | 4:20A - 5:00A     | 250                     | 0.007           |
|              | 5:00A - 9:00A     | 300                     | 0.008           |
|              | 9:00A - Midnite   | 350                     | 0.010           |
| 11-20        | Midnite - 1:30A   | 400                     | 0.012           |
|              | 1:30A - 2:30A     | 300                     | 0.008           |
|              | 2:30A - Midnite   | 250                     | 0.007           |
| 11-21        |                   | 250                     | 0.007           |
| 11-22        |                   | 250-300                 | 0.007-0.008     |
| 11-23        |                   | 250                     | 0.007           |
| 11-24        | Midnite - 8:45A   | 250                     | 0.007           |
|              | 8:45A - Midnite   | 350                     | 0.010           |
| 11-25        | Midnite - 9:00P   | 350                     | 0.010           |
|              | 9:00P - Midnite   | 250                     | 0.007           |
| 11-26        |                   | 250                     | 0.007           |
| 11-27        | 28, 29, 30 (each) | 250                     | 0.007           |

NOTE: The average  $\gamma$  Background level for Oct. and Nov. has remained essentially the same 0.007 mr/hr irrespective of the high peaks.

REPORT OF THE  
LOS ANGELES CITY HEALTH DEPARTMENT

RADIOACTIVE CONCENTRATIONS IN AIR

| <u>Date Filter Removed</u><br><u>From Pump</u> |    | <u>Beta-Gamma Activity</u><br><u><math>\mu\text{c}/\text{M}^3</math></u> | <u>(1)</u> | <u>Average</u><br><u>Per Month</u> |
|------------------------------------------------|----|--------------------------------------------------------------------------|------------|------------------------------------|
| June                                           | 2  | 5.4                                                                      |            |                                    |
|                                                | 3  | 5.1                                                                      |            |                                    |
|                                                | 4  | 8.7                                                                      |            |                                    |
|                                                | 5  | 5.8                                                                      |            |                                    |
|                                                | 6  | 8.8                                                                      |            |                                    |
|                                                | 7  | 5.6                                                                      |            |                                    |
|                                                | 9  | 6.3                                                                      |            |                                    |
|                                                | 10 | 5.1                                                                      |            |                                    |
|                                                | 11 | 4.8                                                                      |            |                                    |
|                                                | 12 | 6.0                                                                      |            |                                    |
|                                                | 13 | 7.6                                                                      |            |                                    |
|                                                | 14 | 6.0                                                                      |            |                                    |
|                                                | 16 | 4.5                                                                      |            |                                    |
|                                                | 17 | 7.3                                                                      |            |                                    |
|                                                | 18 | 8.0                                                                      |            |                                    |
|                                                | 19 | 13.1                                                                     |            |                                    |
|                                                | 20 | 9.3                                                                      |            |                                    |
|                                                | 21 | 9.0                                                                      |            |                                    |
|                                                | 23 | 10.0                                                                     |            |                                    |
|                                                | 24 | 6.8                                                                      |            |                                    |
|                                                | 25 | 10.7                                                                     |            |                                    |
|                                                | 26 | 8.2                                                                      |            |                                    |
|                                                | 27 | 12.7                                                                     |            |                                    |
|                                                | 28 | 9.9                                                                      |            |                                    |
|                                                | 30 | 11.7                                                                     |            |                                    |

7.9

(1) Recorded activity taken on basis of 24 hour decay, after removal from pump.

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RADIOACTIVE CONCENTRATIONS IN AIR

| <u>Date Filter Removed</u><br><u>From Pump</u> |    | <u>Beta-Gamma Activity</u><br><u><math>\mu\text{c}/\text{M}^3</math></u> | <u>(1)</u> | <u>Average</u><br><u>Per Month</u> |
|------------------------------------------------|----|--------------------------------------------------------------------------|------------|------------------------------------|
| July                                           | 1  | 8.2                                                                      |            |                                    |
|                                                | 2  | 6.1                                                                      |            |                                    |
|                                                | 3  | 8.4                                                                      |            |                                    |
|                                                | 5  | 10.7                                                                     |            |                                    |
|                                                | 7  | 9.0                                                                      |            |                                    |
|                                                | 8  | 8.0                                                                      |            |                                    |
|                                                | 9  | 8.5                                                                      |            |                                    |
|                                                | 10 | 9.1                                                                      |            |                                    |
|                                                | 11 | 9.3                                                                      |            |                                    |
|                                                | 14 | 7.7                                                                      |            |                                    |
|                                                | 15 | 7.5                                                                      |            |                                    |
|                                                | 16 | 4.9                                                                      |            |                                    |
|                                                | 17 | 2.9                                                                      |            |                                    |
|                                                | 18 | 5.6                                                                      |            |                                    |
|                                                | 21 | 5.1                                                                      |            |                                    |
|                                                | 22 | 3.6                                                                      |            |                                    |
|                                                | 23 | 3.6                                                                      |            |                                    |
|                                                | 24 | 5.8                                                                      |            |                                    |
|                                                | 25 | 4.9                                                                      |            |                                    |
|                                                | 28 | 4.5                                                                      |            |                                    |
|                                                | 29 | 5.8                                                                      |            |                                    |
|                                                | 30 | 5.9                                                                      |            |                                    |
|                                                | 31 | 11.0                                                                     |            |                                    |
| August                                         | 1  | 13.0                                                                     |            | 6.9                                |
|                                                | 2  | 6.9                                                                      |            |                                    |
|                                                | 4  | 7.9                                                                      |            |                                    |
|                                                | 5  | 6.9                                                                      |            |                                    |
|                                                | 6  | 4.9                                                                      |            |                                    |
|                                                | 7  | 7.0                                                                      |            |                                    |
|                                                | 8  | 9.0                                                                      |            |                                    |
|                                                | 9  | 8.7                                                                      |            |                                    |
|                                                | 11 | 9.8                                                                      |            |                                    |
|                                                | 12 | 8.7                                                                      |            |                                    |
|                                                | 13 | 4.1                                                                      |            |                                    |
|                                                | 14 | 8.0                                                                      |            |                                    |
|                                                | 15 | 3.9                                                                      |            |                                    |
|                                                | 16 | 7.9                                                                      |            |                                    |
|                                                | 18 | 6.0                                                                      |            |                                    |
|                                                | 19 | 2.8                                                                      |            |                                    |
|                                                | 20 | 2.3                                                                      |            |                                    |
|                                                | 21 | 3.1                                                                      |            |                                    |
|                                                | 22 | 3.0                                                                      |            |                                    |
|                                                | 23 | 7.7                                                                      |            |                                    |
|                                                | 25 | 5.7                                                                      |            |                                    |
|                                                | 26 | 8.2                                                                      |            |                                    |
|                                                | 27 | 4.0                                                                      |            |                                    |
|                                                | 28 | 4.2                                                                      |            |                                    |
|                                                | 29 | 5.5                                                                      |            |                                    |

(1) Recorded activity taken on basis of 24 hour decay, after removal from pump.

6.2

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RADIOACTIVE CONCENTRATIONS IN AIR

| Date Filter Removed<br>From Pump | Beta-Gamma Activity<br>$\mu\text{uc}/\text{M}^3$ (1) | Average<br>Per Month |
|----------------------------------|------------------------------------------------------|----------------------|
| Sept. 2                          | 5.4                                                  |                      |
| 3                                | 8.1                                                  |                      |
| 4                                | 5.8                                                  |                      |
| 5                                | 5.4                                                  |                      |
| 6                                | 6.1                                                  |                      |
| 8                                | 5.8                                                  |                      |
| 10                               | 6.9                                                  |                      |
| 11                               | 7.2                                                  |                      |
| 12                               | 4.9                                                  |                      |
| 13                               | 3.7                                                  |                      |
| 15                               | 8.7                                                  |                      |
| 16                               | 7.9                                                  |                      |
| 17                               | 11.9                                                 |                      |
| 18                               | 9.3                                                  |                      |
| 19                               | 9.1                                                  |                      |
| 20                               | 7.2                                                  |                      |
| 22                               | 5.3                                                  |                      |
| 23                               | 5.2                                                  |                      |
| 24                               | 7.5                                                  |                      |
| 25                               | 10.7                                                 |                      |
| 26                               | 14.8                                                 |                      |
| 27                               | 8.5                                                  |                      |
| 29                               | 7.6                                                  |                      |
| 29                               | 13.3                                                 |                      |
| 30                               | 16.2                                                 |                      |
| 30                               | 3.9                                                  |                      |
| Oct. 1                           | 3.7                                                  |                      |
| 2                                | 6.8                                                  |                      |
| 3                                | 12.5                                                 |                      |
| 4                                | 10.3                                                 |                      |
| 6                                | 6.6                                                  |                      |
| 7                                | 7.9                                                  |                      |
| 8                                | 9.6                                                  |                      |
| 9                                | 8.6                                                  |                      |
| 10                               | 5.8                                                  |                      |
| 11                               | 8.7                                                  |                      |
| 13                               | 5.4                                                  |                      |
| 14                               | 5.5                                                  |                      |
| 15                               | 10.1                                                 |                      |
| 16                               | 10.5                                                 |                      |
| 17                               | 8.4                                                  |                      |
| 18                               | 11.4                                                 |                      |
| 20                               | 11.7                                                 |                      |
| 21                               | 14.3                                                 |                      |
| 22                               | 90.3                                                 |                      |
| 22                               | 95.0                                                 |                      |
| 23                               | 124.5                                                |                      |
| 23                               | 86.4                                                 |                      |
| 24                               | 114.0                                                |                      |
|                                  |                                                      | 7.5                  |

(1) Recorded activity taken on basis of 24 hour decay, after removal from pump.

RADIOACTIVE CONCENTRATIONS IN AIR

| Date Filter Removed<br>From Pump | Beta-Gamma Activity<br>$\mu\text{uc}/\text{M}^3$ (1) | Average<br>Per Month |
|----------------------------------|------------------------------------------------------|----------------------|
| Oct. 25                          | 59.8                                                 |                      |
| 26                               | 33.2                                                 |                      |
| 27                               | 25.4                                                 |                      |
| 28                               | 214                                                  |                      |
| 29                               | 320                                                  |                      |
| 30                               | 920                                                  |                      |
| 31                               | 363                                                  |                      |
|                                  |                                                      | 80.7                 |
| Nov. 1                           | 83.5                                                 |                      |
| 3                                | 170                                                  |                      |
| 4                                | 683                                                  |                      |
| 5                                | 689                                                  |                      |
| 6                                | 471                                                  |                      |
| 7                                | 457                                                  |                      |
| 8                                | 191.5                                                |                      |
| 8                                | 131.1                                                |                      |
| 9                                | 88.2                                                 |                      |
| 10                               | 80.2                                                 |                      |
| 11                               | 28.6                                                 |                      |
| 12                               | 47.9                                                 |                      |
| 13                               | 50.0                                                 |                      |
| 14                               | 32.2                                                 |                      |
| 15                               | 23.1                                                 |                      |
| 16                               | 14.3                                                 |                      |
| 17                               | 7.0                                                  |                      |
| 18                               | 31.7                                                 |                      |
| 19                               | 46.0                                                 |                      |
| 20                               | 66.4                                                 |                      |
| 21                               | 63.7                                                 |                      |
| 22                               | 41.6                                                 |                      |
| 23                               | 58.5                                                 |                      |
| 24                               | 36.7                                                 |                      |
| 25                               | 18.3                                                 |                      |
| 26                               | 16.0                                                 |                      |
| 28                               | 23.2                                                 |                      |
| 29                               | 52.5                                                 |                      |
|                                  |                                                      | 132.2                |

(1) Recorded activity taken on basis of 24 hour decay, after removal from pump.

REPORT OF THE  
LOS ANGELES CITY HEALTH DEPARTMENT

DECAY RATES FOR AIR SAMPLES

| Date Assayed | Time Assayed | Hours Decay | $\mu\text{uc}/\text{M}^3$ |
|--------------|--------------|-------------|---------------------------|
| 10/22/58     | 9:50 a.m.    | 0           | 111.0                     |
| 10/22/58     | 3:50 p.m.    | 6           | 107.2                     |
| 10/23/58     | 8:00 a.m.    | 24          | 90.5                      |
| 10/24/58     | 8:45 a.m.    | 35          | 83.7                      |
| 10/25/58     | 10:25 a.m.   | 60          | 62.5                      |
| 10/26/58     | 9:50 a.m.    | 83          | 63.1                      |
| 10/27/58     | 10:00 a.m.   | 107         | 60.9                      |
| 10/29/58     | 8:30 a.m.    | 153         | 50.6                      |
| 10/31/58     | 9:00 a.m.    | 177         | 44.4                      |
| 11/03/58     | 12:45 p.m.   | 253         | 39.3                      |
| 10/22/58     | 5:10 p.m.    | 0           | 143.5                     |
| 10/23/58     | 8:00 a.m.    | 15          | 103.5                     |
| 10/23/58     | 3:25 p.m.    | 22          | 95.0                      |
| 10/24/58     | 8:20 a.m.    | 39          | 93.5                      |
| 10/25/58     | 10:35 a.m.   | 65          | 84.7                      |
| 10/26/58     | 10:00 a.m.   | 89          | 75.1                      |
| 10/27/58     | 9:30 a.m.    | 112         | 68.4                      |
| 10/29/58     | 9:10 a.m.    | 160         | 65.1                      |
| 10/23/58     | 8:14 a.m.    | 0           | 187.0                     |
| 10/23/58     | 2:00 p.m.    | 6           | 140.2                     |
| 10/24/58     | 8:05 a.m.    | 24          | 124.5                     |
| 10/25/58     | 10:45 a.m.   | 51          | 1117.8                    |
| 10/26/58     | 10:35 a.m.   | 75          | 99.6                      |
| 10/27/58     | 9:15 a.m.    | 98          | 102.0                     |
| 10/29/58     | 9:45 a.m.    | 146         | 93.5                      |
| 11/03/58     | 1:20 p.m.    | 269         | 74.2                      |
| 10/23/58     | 4:30 p.m.    | 0           | 130.0                     |
| 10/24/58     | 7:50 a.m.    | 15          | 76.0                      |
| 10/24/58     | 4:20 p.m.    | 24          | 86.4                      |
| 10/25/58     | 10:55 a.m.   | 43          | 80.5                      |
| 10/26/58     | 10:45 a.m.   | 67          | 69.8                      |
| 10/27/58     | 8:45 a.m.    | 90          | 61.2                      |
| 10/29/58     | 10:15 a.m.   | 139         | 60.9                      |
| 10/24/58     | 7:40 a.m.    | 0           | 214.0                     |
| 10/24/58     | 2:00 p.m.    | 6           | 129.0                     |
| 10/25/58     | 11:10 a.m.   | 27          | 114.0                     |
| 10/26/58     | 11:00 a.m.   | 51          | 100.0                     |
| 10/27/58     | 8:30 a.m.    | 72          | 94.3                      |
| 10/29/58     | 11:00 a.m.   | 123         | 88.3                      |
| 11/03/58     | 2:10 p.m.    | 246         | 67.3                      |

DECAY RATES FOR AIR SAMPLES

| Date Assayed | Time Assayed | Hours Decay | $\mu\text{uc}/\text{M}^3$ |
|--------------|--------------|-------------|---------------------------|
| 10/25/58     | 10:15 a.m.   | 0           | 66.4                      |
| 10/26/58     | 11:20 a.m.   | 25          | 60.0                      |
| 10/27/58     | 8:15 a.m.    | 46          | 56.0                      |
| 10/28/58     | 8:30 a.m.    | 70          | 51.2                      |
| 10/29/58     | 11:30 a.m.   | 97          | 47.1                      |
| 10/30/58     | 10:10 a.m.   | 120         | 46.0                      |
| 11/03/58     | 3:25 p.m.    | 221         | 37.6                      |
| 10/26/58     | 9:40 a.m.    | 0           | 87.3                      |
| 10/27/58     | 7:50 a.m.    | 22          | 39.2                      |
| 10/28/58     | 9:00 a.m.    | 47          | 29.6                      |
| 10/29/58     | 8:40 p.m.    | 70          | 21.8                      |
| 10/30/58     | 11:10 a.m.   | 96          | 20.2                      |
| 11/03/58     | 4:01 p.m.    | 197         | 15.5                      |
| 10/27/58     | 7:40 a.m.    | 0           | 117.0                     |
| 10/28/58     | 7:35 a.m.    | 24          | 25.4                      |
| 10/29/58     | 2:00 p.m.    | 54          | 20.6                      |
| 10/30/58     | 12:05 p.m.   | 76          | 18.25                     |
| 11/03/58     | 11:50 a.m.   | 172         | 14.0                      |
| 10/28/58     | 7:50 a.m.    | 0           | 407.0                     |
| 10/28/58     | 10:35 a.m.   | 3           | 312.0                     |
| 10/28/58     | 12:30 p.m.   | 5           | 298.0                     |
| 10/28/58     | 2:10 p.m.    | 7           | 272.0                     |
| 10/29/58     | 7:50 a.m.    | 24          | 214.0                     |
| 10/29/58     | 9:15 p.m.    | 37          | 181.5                     |
| 10/30/58     | 1:40 p.m.    | 54          | 159.2                     |
| 10/31/58     | 9:40 a.m.    | 74          | 131.0                     |
| 10/31/58     | 3:00 p.m.    | 79          | 130.5                     |
| 11/01/58     | 9:25 a.m.    | 98          | 110.5                     |
| 11/02/58     | 9:35 a.m.    | 122         | 99.8                      |
| 11/03/58     | 10:45 a.m.   | 147         | 87.7                      |
| 10/29/58     | 7:40 a.m.    | 0           | 501.0                     |
| 10/29/58     | 11:55 a.m.   | 4           | 372.0                     |
| 10/29/58     | 3:00 p.m.    | 7           | 391.0                     |
| 10/29/58     | 3:40 p.m.    | 8           | 386.0                     |
| 10/29/58     | 5:25 p.m.    | 10          | 379.0                     |
| 10/29/58     | 7:40 p.m.    | 12          | 350.0                     |
| 10/29/58     | 9:30 p.m.    | 14          | 366.0                     |
| 10/30/58     | 7:50 a.m.    | 24          | 320.0                     |
| 10/30/58     | 12:55 p.m.   | 29          | 302.0                     |
| 10/30/58     | 5:35 p.m.    | 34          | 284.0                     |
| 10/30/58     | 8:40 p.m.    | 37          | 286.0                     |
| 10/30/58     | 9:15 p.m.    | 37.5        | 283.5                     |
| 10/31/58     | 8:15 a.m.    | 48          | 258.                      |
| 10/31/58     | 2:45 p.m.    | 54          | 240.                      |
| 11/01/58     | 9:05 a.m.    | 73          | 214.                      |

## DECAY RATES FOR AIR SAMPLES

| Date Assayed | Time Assayed | Hours Decay | $\mu\text{uc}/\text{M}^3$ |
|--------------|--------------|-------------|---------------------------|
| 11/02/58     | 9:20 a.m.    | 97          | 188.                      |
| 11/03/58     | 10:20 a.m.   | 122         | 163.3                     |
| 11/04/58     | 9:40 a.m.    | 145         | 143.5                     |
| 11/05/58     | 9:55 a.m.    | 169         | 128.0                     |
| 11/06/58     | 10:40 a.m.   | 194         | 114.3                     |
| 10/30/58     | 7:40 a.m.    | 0           | 2220.0                    |
| 10/30/58     | 9:15 a.m.    | 2           | 1950.0                    |
| 10/30/58     | 9:25 a.m.    | 2           | 1955.0                    |
| 10/30/58     | 12:35 p.m.   | 5           | 1710.0                    |
| 10/30/58     | 2:30 p.m.    | 7           | 1540.0                    |
| 10/30/58     | 5:25 p.m.    | 10          | 1340.0                    |
| 10/30/58     | 8:55 p.m.    | 13          | 1190.0                    |
| 10/30/58     | 9:05 p.m.    | 13.5        | 1178.0                    |
| 10/31/58     | 8:00 a.m.    | 24          | 920.0                     |
| 10/31/58     | 2:30 p.m.    | 30.5        | 765.0                     |
| 10/31/58     | 7:45 p.m.    | 36          | 701.0                     |
| 11/01/58     | 8:45 a.m.    | 49          | 553.0                     |
| 11/02/58     | 9:00 a.m.    | 73          | 422.0                     |
| 11/03/58     | 10:05 a.m.   | 98          | 351.0                     |
| 11/04/58     | 9:40 a.m.    | 122         | 280.0                     |
| 11/05/58     | 9:35 a.m.    | 146         | 248.0                     |
| 11/06/58     | 10:25 a.m.   | 171         | 208.0                     |
| 11/07/58     | 11:50 a.m.   | 196         | 196.0                     |
| 10/31/58     | 7:25 a.m.    | 0           | 614.0                     |
| 10/31/58     | 1:55 p.m.    | 6           | 469.0                     |
| 10/31/58     | 4:35 p.m.    | 9           | 450.0                     |
| 10/31/58     | 8:30 p.m.    | 13          | 427.0                     |
| 11/01/58     | 7:50 a.m.    | 24          | 363.0                     |
| 11/02/58     | 8:40 a.m.    | 49          | 276.0                     |
| 11/03/58     | 9:35 a.m.    | 74          | 240.0                     |
| 11/04/58     | 9:00 a.m.    | 98          | 208.0                     |
| 11/05/58     | 9:10 a.m.    | 122         | 182.5                     |
| 11/06/58     | 10:00 a.m.   | 147         | 159.5                     |
| 11/07/58     | 11:20 a.m.   | 172         | 149.5                     |
| 11/01/58     | 7:40 a.m.    | 0           | 198.0                     |
| 11/02/58     | 7:55 a.m.    | 24          | 83.5                      |
| 11/03/58     | 8:50 a.m.    | 49          | 75.3                      |
| 11/04/58     | 8:35 a.m.    | 73          | 64.5                      |
| 11/05/58     | 8:50 a.m.    | 97          | 58.5                      |
| 11/06/58     | 9:40 a.m.    | 122         | 54.6                      |
| 11/07/58     | 10:25 a.m.   | 147         | 48.8                      |

## DECAY RATES FOR AIR SAMPLES

| Date Assayed | Time Assayed | Hours Decay | $\mu\text{uc}/\text{M}^3$ |
|--------------|--------------|-------------|---------------------------|
| 11/02/58     | 7:45 a.m.    | 0           | 307.0                     |
| 11/03/58     | 7:45 a.m.    | 24          | 170.0                     |
| 11/04/58     | 8:20 a.m.    | 49          | 143.5                     |
| 11/05/58     | 8:25 a.m.    | 73          | 127.5                     |
| 11/06/58     | 9:20 a.m.    | 98          | 113.0                     |
| 11/07/58     | 10:00 a.m.   | 123         | 98.0                      |
| 11/03/58     | 7:35 a.m.    | 0           | 1000.0                    |
| 11/03/58     | 11:40 a.m.   | 4           | 847.0                     |
| 11/03/58     | 2:55 p.m.    | 7           | 807.0                     |
| 11/03/58     | 5:05 p.m.    | 9           | 795.0                     |
| 11/04/58     | 7:20 a.m.    | 24          | 683.0                     |
| 11/05/58     | 8:00 a.m.    | 49          | 572.0                     |
| 11/06/58     | 9:00 a.m.    | 74          | 493.0                     |
| 11/07/58     | 9:35 a.m.    | 98          | 429.0                     |
| 11/04/58     | 7:40 a.m.    | 0           | 850.0                     |
| 11/04/58     | 10:35 a.m.   | 3           | 790.0                     |
| 11/04/58     | 6:55 p.m.    | 11          | 754.0                     |
| 11/05/58     | 7:50 a.m.    | 24          | 689.0                     |
| 11/06/58     | 8:35 a.m.    | 49          | 555.0                     |
| 11/07/58     | 9:15 a.m.    | 74          | 489.0                     |
| 11/05/58     | 7:40 a.m.    | 0           | 700.0                     |
| 11/05/58     | 10:35 a.m.   | 3           | 550.0                     |
| 11/05/58     | 11:25 a.m.   | 4           | 555.0                     |
| 11/05/58     | 12:25 p.m.   | 4.5         | 538.0                     |
| 11/05/58     | 12:55 p.m.   | 5           | 545.0                     |
| 11/05/58     | 1:20 p.m.    | 6           | 549.0                     |
| 11/05/58     | 4:00 p.m.    | 9           | 543.0                     |
| 11/06/58     | 7:50 a.m.    | 24          | 471.0                     |
| 11/07/58     | 8:50 a.m.    | 49          | 382.0                     |
| 11/06/58     | 7:30 a.m.    | 0           | 457.0                     |
| 11/06/58     | 11:20 a.m.   | 4           | 358.0                     |
| 11/06/58     | 4:15 p.m.    | 9           | 344.0                     |
| 11/07/58     | 8:10 a.m.    | 25          | 299.0                     |
| 11/08/58     | 11:40 a.m.   | 52          | 257.0                     |
| 11/09/58     | 10:50 a.m.   | 75          | 233.0                     |
| 11/10/58     | 8:35 a.m.    | 97          | 220.0                     |
| 11/12/58     | 10:20 a.m.   | 147         | 185.2                     |
| 11/13/58     | 10:50 a.m.   | 171         | 176.0                     |
| 11/17/58     | 12:40 p.m.   | 269         | 130.8                     |
| 11/07/58     | 7:45 a.m.    | 0           | 289.0                     |
| 11/07/58     | 1:45 p.m.    | 6           | 206.0                     |
| 11/08/58     | 10:15 a.m.   | 27          | 191.5                     |
| 11/09/58     | 10:35 a.m.   | 51          | 168.9                     |
| 11/10/58     | 8:15 a.m.    | 73          | 160.                      |

DECAY RATES FOR AIR SAMPLES

| <u>Date Assayed</u> | <u>Time Assayed</u> | <u>Hours Decay</u> | <u><math>\mu\text{C}/\text{M}^3</math></u> |
|---------------------|---------------------|--------------------|--------------------------------------------|
| 11/11/58            | 11:30 a.m.          | 100                | 145.5                                      |
| 11/12/58            | 10:05 a.m.          | 123                | 134.0                                      |
| 11/13/58            | 10:45 a.m.          | 148                | 122.6                                      |
| 11/17/58            | 12:15 p.m.          | 246                | 97.9                                       |
| 11/08/58            | 10:25 a.m.          | 0                  | 197.0                                      |
| 11/09/58            | 10:25 a.m.          | 24                 | 131.1                                      |
| 11/10/58            | 7:55 a.m.           | 45.5               | 121.5                                      |
| 11/11/58            | 11:15 a.m.          | 73                 | 111.0                                      |
| 11/12/58            | 9:50 a.m.           | 96                 | 105.2                                      |
| 11/13/58            | 10:10 a.m.          | 120                | 102.5                                      |
| 11/09/58            | 10:15 a.m.          | 0                  | 148.3                                      |
| 11/10/58            | 7:35 a.m.           | 21                 | 88.2                                       |
| 11/11/58            | 11:00 a.m.          | 49                 | 77.5                                       |
| 11/12/58            | 9:10 a.m.           | 71                 | 73.0                                       |
| 11/13/58            | 9:25 a.m.           | 95                 | 69.4                                       |
| 11/14/58            | 10:00 a.m.          | 120                | 61.7                                       |
| 11/10/58            | 7:20 a.m.           | 0                  | 117.0                                      |
| 11/11/58            | 10:40 a.m.          | 27                 | 80.2                                       |
| 11/12/58            | 8:45 a.m.           | 49                 | 74.5                                       |
| 11/13/58            | 9:00 a.m.           | 73                 | 68.2                                       |
| 11/14/58            | 9:35 a.m.           | 98                 | 67.6                                       |
| 11/17/58            | 10:50 a.m.          | 123.5              | 54.1                                       |
| 11/11/58            | 10:05 a.m.          | 0                  | 44.4                                       |
| 11/12/58            | 8:00 a.m.           | 22                 | 28.6                                       |
| 11/13/58            | 8:00 a.m.           | 46                 | 23.9                                       |
| 11/14/58            | 8:50 a.m.           | 71                 | 21.4                                       |
| 11/17/58            | 10:30 a.m.          | 145                | 17.3                                       |

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REPORT OF  
LOS ANGELES CITY HEALTH DEPARTMENT

RAIN

| <u>Date</u> | <u>Hours of Rainfall</u> | <u><math>\mu\text{C}/\text{l}</math> (1)</u> |
|-------------|--------------------------|----------------------------------------------|
| 3/14-15/58  | 7:45 a.m. to 2:15 p.m.   | 69.0                                         |
| 3/15-17/58  | 2:15 p.m. to 8:05 a.m.   | 116.                                         |
| 3/20-21/58  | 8:00 a.m. to 7:00 a.m.   | 214.                                         |
| 3/21-22/58  | 7:00 a.m. to 1:00 p.m.   | 854.                                         |
| 3/27/58     | 8:00 a.m. to 9:00 a.m.   | 1415.                                        |
| 3/27/58     | 9:00 a.m. to 12:00 noon  | 1775.                                        |
| 3/29-31/58  | 9:30 a.m. to 8:00 a.m.   | 864.                                         |
| 3/31-4/1/58 | 8:00 a.m. to 8:00 a.m.   | 345.                                         |
| 4/1/58      | 8:00 a.m. to 10:00 a.m.  | 258.                                         |
| 4/1-2/58    | 10:00 a.m. to 8:00 a.m.  | 334.                                         |
| 4/2-3/58    | 8:00 a.m. to 8:00 a.m.   | 407.                                         |
| 4/3-4/58    | 8:00 a.m. to 7:30 a.m.   | 330.                                         |
| 4/5-7/58    | 10:30 a.m. to 8:00 a.m.  | 342.                                         |
| 8/15/58     | 8:00 a.m. to 10:30 a.m.  | 1575.                                        |
| 8/15/58     | 10:30 a.m. to 3:00 p.m.  | 1655.                                        |
| 9/23-24/58  | 4:30 p.m. to 7:00 a.m.   | 1505. *                                      |
| 10/24-25/58 | 4:00 p.m. to 9:30 a.m.   | 5490.                                        |
|             | 26 hours decay           | 5020                                         |
|             | 46 " "                   | 4730                                         |
|             | 93 " "                   | 3860                                         |
|             | 116 " "                  | 3420                                         |
|             | 284 " "                  | 2330                                         |

(1) Based on 500 ml sample

\* Based on 170 ml sample

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REPORT OF  
LOS ANGELES DEPARTMENT OF WATER AND POWER

RADIOACTIVITY IN AIR

Using California Disaster Office Filters

| <u>24 hour sampling<br/>ending at</u> | <u>Date - time of<br/>measurement</u> | <u>Activity, gross beta-gamma, as<br/>micro-microcuries per cu. meter</u> |
|---------------------------------------|---------------------------------------|---------------------------------------------------------------------------|
| 10-14-58, 1:00 p.m.                   | 141300                                | 2.7                                                                       |
| 10-15-58, 1:00 p.m.                   | 151300                                | 3.0                                                                       |
| 10-16-58, 1:00 p.m.                   | 161300                                | 3.8                                                                       |
| "                                     | 171300                                | 2.9                                                                       |
| 10-17-58, 1:00 p.m.                   | 171345                                | 12.1                                                                      |
| "                                     | 201500                                | 3.0                                                                       |
| 10-18-58, 1:00 p.m.                   | 201400                                | 2.8                                                                       |
| 10-19-58, 1:00 p.m.                   | 201300                                | 4.9                                                                       |
| 10-20-58, 1:00 p.m.                   | 201345                                | 12.3                                                                      |
| "                                     | 211300                                | 4.4                                                                       |
| 10-21-58, 1:00 p.m.                   | 211345                                | 19.5                                                                      |
| "                                     | 221300                                | 12.2                                                                      |
| "                                     | 231320                                | 12.5                                                                      |
| "                                     | 240955                                | 11.5                                                                      |
| 10-22-58, 1:00 p.m.                   | 221345                                | 26.1                                                                      |
| "                                     | 231300                                | 18.5                                                                      |
| "                                     | 240940                                | 16.1                                                                      |
| "                                     | 271245                                | 12.2                                                                      |
| 10-23-58, 1:00 p.m.                   | 231345                                | 54.3                                                                      |
| "                                     | 240930                                | 42.7                                                                      |
| "                                     | 271235                                | 32.7                                                                      |
| "                                     | 281440                                | 28.8                                                                      |
| "                                     | 291430                                | 24.8                                                                      |
| 10-24-58, 1:00 p.m.                   | 241345                                | 31.5                                                                      |
| "                                     | 271225                                | 19.7                                                                      |
| "                                     | 281430                                | 20.5                                                                      |
| "                                     | 291400                                | 17.6                                                                      |
| "                                     | 301230                                | 16.7                                                                      |
| "                                     | 311335                                | 15.5                                                                      |
| 10-25-58, 1:00 p.m.                   | 271200                                | 7.9                                                                       |
| "                                     | 281315                                | 7.8                                                                       |
| "                                     | 291200                                | 7.3                                                                       |
| "                                     | 301205                                | 6.6                                                                       |
| "                                     | 311430                                | 55.9                                                                      |
| 10-26-58, 1:00 p.m.                   | 271300                                | 6.6                                                                       |
| "                                     | 281400                                | 6.3                                                                       |
| "                                     | 291030                                | 5.7                                                                       |
| "                                     | 301135                                | 4.9                                                                       |
| "                                     | 311350                                | 4.7                                                                       |
| 10-27-58, 1:00 p.m.                   | 271345                                | 25.9                                                                      |
| "                                     | 281300                                | 13.1                                                                      |
| "                                     | 291310                                | 7.6                                                                       |
| "                                     | 301115                                | 9.3                                                                       |
| "                                     | 311315                                | 8.1                                                                       |

| <u>24 hour sampling<br/>ending at</u> | <u>Date - time of<br/>measurement</u> | <u>Activity, gross beta-gamma, as<br/>micro-microcuries per cu. meter</u> |
|---------------------------------------|---------------------------------------|---------------------------------------------------------------------------|
| 10-28-58, 1:00 p.m.                   | 281345                                | 76.1                                                                      |
| "                                     | 291300                                | 57.1                                                                      |
| "                                     | 301105                                | 33.7                                                                      |
| "                                     | 311305                                | 27.0                                                                      |
| "                                     | 011230                                | 23.9                                                                      |
| "                                     | 021245                                | 19.1                                                                      |
| "                                     | 031350                                | 18.5                                                                      |
| "                                     | 041405                                | 17.2                                                                      |
| 10-29-58, 1:00 p.m.                   | 291345                                | 41.1                                                                      |
| "                                     | 301245                                | 32.0                                                                      |
| "                                     | 311230                                | 27.3                                                                      |
| "                                     | 011210                                | 24.8                                                                      |
| "                                     | 021210                                | 21.0                                                                      |
| "                                     | 031325                                | 19.5                                                                      |
| "                                     | 041350                                | 19.3                                                                      |
| "                                     | 051405                                | 18.7                                                                      |
| 10-30-58, 1:00 p.m.                   | 301300                                | 633                                                                       |
| "                                     | 311255                                | 345                                                                       |
| "                                     | 011200                                | 233                                                                       |
| "                                     | 021200                                | 178                                                                       |
| "                                     | 031320                                | 144                                                                       |
| "                                     | 041335                                | 125                                                                       |
| "                                     | 051340                                | 111                                                                       |
| "                                     | 061422                                | 101                                                                       |
| 10-31-58, 1:00 p.m.                   | 311345                                | 40.2                                                                      |
| "                                     | 011300                                | 30.6                                                                      |
| "                                     | 021330                                | 24.5                                                                      |
| "                                     | 031310                                | 22.9                                                                      |
| "                                     | 041322                                | 22.3                                                                      |
| "                                     | 051335                                | 19.4                                                                      |
| "                                     | 061412                                | 17.9                                                                      |
| 11-1-58, 1:00 p.m.                    | 011345                                | 40.2                                                                      |
| "                                     | 021300                                | 23.5                                                                      |
| "                                     | 031230                                | 23.3                                                                      |
| "                                     | 041308                                | 18.6                                                                      |
| "                                     | 051320                                | 18.5                                                                      |
| "                                     | 061400                                | 17.9                                                                      |
| "                                     | 071405                                | 16.2                                                                      |
| 11-2-58, 1:00 p.m.                    | 021345                                | 105                                                                       |
| "                                     | 031300                                | 75.8                                                                      |
| "                                     | 041304                                | 68.3                                                                      |
| "                                     | 051310                                | 58.8                                                                      |
| "                                     | 061335                                | 52.7                                                                      |
| "                                     | 071337                                | 47.8                                                                      |
| "                                     | 081415                                | 36.6                                                                      |

| <u>24 hour sampling<br/>ending at</u> | <u>Date - time of<br/>measurement</u> | <u>Activity, gross beta-gamma, as<br/>micro-microcuries per cu. meter</u> |
|---------------------------------------|---------------------------------------|---------------------------------------------------------------------------|
| 11-3-58, 1:00 p.m.                    | 031345                                | 262                                                                       |
| "                                     | 041300                                | 211                                                                       |
| "                                     | 051305                                | 177                                                                       |
| "                                     | 061320                                | 164                                                                       |
| "                                     | 071335                                | 135                                                                       |
| "                                     | 101410                                | 108                                                                       |
| 11-4-58, 1:00 p.m.                    | 041345                                | 180                                                                       |
| "                                     | 051300                                | 143                                                                       |
| "                                     | 051310                                | 123                                                                       |
| "                                     | 071325                                | 108                                                                       |
| "                                     | 101405                                | 76.3                                                                      |
| 11-5-58, 1:00 p.m.                    | 051345                                | 144                                                                       |
| "                                     | 061300                                | 115                                                                       |
| "                                     | 071305                                | 99.0                                                                      |
| "                                     | 101355                                | 71.2                                                                      |
| 11-6-58, 1:00 p.m.                    | 061345                                | 80.0                                                                      |
| "                                     | 071300                                | 60.4                                                                      |
| "                                     | 101335                                | 41.3                                                                      |
| 11-7-58, 1:00 p.m.                    | 071345                                | 52.6                                                                      |
| "                                     | 101325                                | 27.4                                                                      |
| 11-8-58, 1:00 p.m.                    | 101310                                | 17.3                                                                      |
| "                                     | 121340                                | 26.6                                                                      |
| 11-9-58, 1:00 p.m.                    | 101300                                | 27.1                                                                      |
| "                                     | 121325                                | 22.5                                                                      |
| "                                     | 131420                                | 20.6                                                                      |
| 11-10-58, 1:00 p.m.                   | 101345                                | 22.4                                                                      |
| "                                     | 121300                                | 17.4                                                                      |
| "                                     | 131405                                | 17.1                                                                      |
| 11-11-58, 1:00 p.m.                   | 121230                                | 13.2                                                                      |
| 11-12-58, 1:00 p.m.                   | 131300                                | 23.7                                                                      |
| 11-13-58, 1:00 p.m.                   | 171510                                | 27.2                                                                      |
| 11-14-58, 1:00 p.m.                   | 171425                                | 3.2                                                                       |
| 11-15-58, 1:00 p.m.                   | 171405                                | 7.0                                                                       |
| 11-16-58, 1:00 p.m.                   | 177300                                | 3.2                                                                       |

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REPORT OF  
LOS ANGELES DEPARTMENT OF WATER AND POWER

RADIOACTIVITY IN AIR

Sampled With Millipore Type AA Filter

| <u>24 Hour Sampling<br/>Ending At</u> | <u>Date-Time of<br/>Measurement</u> | <u>Activity, gross beta-gamma,<br/>as micro-microcuries per cu. meter</u> |
|---------------------------------------|-------------------------------------|---------------------------------------------------------------------------|
| 10-14-58, 8:30 a.m.                   | 140915                              | 20.0                                                                      |
| "                                     | 150730                              | 4.3                                                                       |
| 10-15-58, 8:30 a.m.                   | 150915                              | 3.2                                                                       |
| 10-16-58, 8:30 a.m.                   | 160830                              | 26.7                                                                      |
| "                                     | 160915                              | 16.1                                                                      |
| "                                     | 170840                              | 4.3                                                                       |
| 10-17-58, 8:30 a.m.                   | 170830                              | 30.5                                                                      |
| "                                     | 170915                              | 18.9                                                                      |
| 10-18-58, 8:30 a.m.                   | 200840                              | 4.1                                                                       |
| 10-19-58, 8:30 a.m.                   | 200840                              | 5.2                                                                       |
| "                                     | 210730                              | 3.4                                                                       |
| 10-20-58, 8:30 a.m.                   | 200830                              | 28.4                                                                      |
| "                                     | 200915                              | 19.0                                                                      |
| "                                     | 210840                              | 6.5                                                                       |
| 10-21-58, 8:30 a.m.                   | 210830                              | 51.3                                                                      |
| "                                     | 210915                              | 42.7                                                                      |
| "                                     | 220835                              | 21.9                                                                      |
| "                                     | 230840                              | 18.2                                                                      |
| "                                     | 240815                              | 16.4                                                                      |
| "                                     | 270815                              | 11.5                                                                      |
| 10-22-58, 8:30 a.m.                   | 220830                              | 92.1                                                                      |
| "                                     | 220915                              | 66.2                                                                      |
| "                                     | 230730                              | 45.7                                                                      |
| "                                     | 240730                              | 40.9                                                                      |
| "                                     | 270800                              | 29.6                                                                      |
| 10-23-58, 8:30 a.m.                   | 230830                              | 88.5                                                                      |
| "                                     | 230915                              | 78.6                                                                      |
| "                                     | 240925                              | 55.5                                                                      |
| "                                     | 270745                              | 43.7                                                                      |
| "                                     | 280815                              | 39.4                                                                      |
| "                                     | 291105                              | 32.1                                                                      |
| "                                     | 300855                              | 31.5                                                                      |
| 10-24-58, 8:30 a.m.                   | 240830                              | 70.8                                                                      |
| "                                     | 240915                              | 54.0                                                                      |
| "                                     | 270730                              | 31.6                                                                      |
| "                                     | 280810                              | 27.1                                                                      |
| "                                     | 290900                              | 27.1                                                                      |
| "                                     | 300845                              | 24.8                                                                      |
| 10-25-58, 8:30 a.m.                   | 270930                              | 20.0                                                                      |
| "                                     | 280740                              | 18.5                                                                      |
| "                                     | 290805                              | 18.5                                                                      |
| "                                     | 300730                              | 16.1                                                                      |
| "                                     | 310840                              | 15.9                                                                      |
| 10-26-58, 8:30 a.m.                   | 270925                              | 26.3                                                                      |
| "                                     | 280750                              | 20.4                                                                      |
| "                                     | 290750                              | 20.5                                                                      |

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| 24 Hour Sampling<br>Ending at | Date-Time of<br>Measurement | Activity, gross beta-gamma,<br>as micro-microcuries per cubic meter |
|-------------------------------|-----------------------------|---------------------------------------------------------------------|
| 10-26-58, 8:30 a.m.           | 300750                      | 12.5                                                                |
| 10-27-58, 8:30 a.m.           | 270830                      | 50.2                                                                |
| "                             | 270915                      | 36.4                                                                |
| "                             | 280755                      | 14.2                                                                |
| "                             | 290840                      | 9.4                                                                 |
| "                             | 300810                      | 8.1                                                                 |
| 10-28-58, 8:30 a.m.           | 280830                      | 81.5                                                                |
| "                             | 280915                      | 75.9                                                                |
| "                             | 281115                      | 55.8                                                                |
| "                             | 281530                      | 51.4                                                                |
| "                             | 290820                      | 36.5                                                                |
| "                             | 300820                      | 25.0                                                                |
| "                             | 310735                      | 22.6                                                                |
| "                             | 010745                      | 18.3                                                                |
| 10-29-58, 8:30 a.m.           | 290830                      | 132.                                                                |
| "                             | 290915                      | 118.                                                                |
| "                             | 291100                      | 101.                                                                |
| "                             | 300825                      | 81.7                                                                |
| "                             | 310725                      | 70.9                                                                |
| "                             | 010800                      | 58.7                                                                |
| "                             | 020850                      | 47.2                                                                |
| "                             | 030820                      | 34.3                                                                |
| "                             | 040805                      | 39.8                                                                |
| "                             | 050850                      | 36.5                                                                |
| "                             | 060820                      | 34.4                                                                |
| 10-30-58, 8:30 a.m.           | 300830                      | 1140                                                                |
| "                             | 300915                      | 759                                                                 |
| "                             | 301100                      | 759                                                                 |
| "                             | 301200                      | 713                                                                 |
| "                             | 301300                      | 670                                                                 |
| "                             | 301600                      | 565                                                                 |
| "                             | 310800                      | 421                                                                 |
| "                             | 010805                      | 255                                                                 |
| "                             | 020848                      | 110                                                                 |
| "                             | 030815                      | 173                                                                 |
| "                             | 040800                      | 140                                                                 |
| "                             | 050845                      | 122                                                                 |
| "                             | 060817                      | 109                                                                 |
| 10-31-58, 8:30 a.m.           | 310830                      | 161                                                                 |
| "                             | 310915                      | 140                                                                 |
| "                             | 010810                      | 88.4                                                                |
| "                             | 020845                      | 69.7                                                                |
| "                             | 030800                      | 60.3                                                                |
| "                             | 040855                      | 54.0                                                                |
| "                             | 050840                      | 50.3                                                                |
| "                             | 060812                      | 44.7                                                                |
| 11-1-58, 8:30 a.m.            | 010830                      | 75.8                                                                |
| "                             | 010915                      | 62.4                                                                |

| 24 Hour Sampling<br>Ending at | Date-Time of<br>Measurement | Activity, gross beta-gamma,<br>as micro-microcuries per cu. meter |
|-------------------------------|-----------------------------|-------------------------------------------------------------------|
| 11-1-58, 8:30 a.m.            | 020840                      | 33.5                                                              |
| "                             | 030750                      | 24.1                                                              |
| "                             | 040845                      | 26.4                                                              |
| "                             | 050815                      | 25.9                                                              |
| "                             | 060805                      | 23.5                                                              |
| "                             | 070930                      | 20.9                                                              |
| 11-2-58, 8:30 a.m.            | 020830                      | 158.                                                              |
| "                             | 020915                      | 116.                                                              |
| "                             | 030745                      | 84.8                                                              |
| "                             | 040740                      | 84.8                                                              |
| "                             | 050810                      | 70.8                                                              |
| "                             | 060855                      | 58.7                                                              |
| "                             | 070900                      | 52.8                                                              |
| 11-3-58, 8:30 a.m.            | 030830                      | 324.                                                              |
| "                             | 030915                      | 324.                                                              |
| "                             | 031300                      | 287.                                                              |
| "                             | 031600                      | 287.                                                              |
| "                             | 040820                      | 260.                                                              |
| "                             | 050808                      | 219.                                                              |
| "                             | 060753                      | 183.                                                              |
| "                             | 070815                      | 167.                                                              |
| "                             | 100940                      | 123.                                                              |
| 11-4-58, 8:30 a.m.            | 040830                      | 214.                                                              |
| "                             | 040915                      | 202.                                                              |
| "                             | 041530                      | 189.                                                              |
| "                             | 050805                      | 179.                                                              |
| "                             | 060750                      | 144.                                                              |
| "                             | 070810                      | 125.                                                              |
| "                             | 100930                      | 91.8                                                              |
| 11-5-58, 8:30 a.m.            | 050830                      | 81.6                                                              |
| "                             | 050915                      | 59.9                                                              |
| "                             | 051515                      | 58.3                                                              |
| "                             | 060745                      | 55.3                                                              |
| "                             | 070800                      | 50.3                                                              |
| "                             | 100905                      | 33.5                                                              |
| 11-6-58, 8:30 a.m.            | 060830                      | 161.                                                              |
| "                             | 060915                      | 131.                                                              |
| "                             | 070740                      | 94.5                                                              |
| "                             | 100840                      | 77.4                                                              |
| "                             | 121050                      | 54.0                                                              |
| 11-7-58, 8:30 a.m.            | 070830                      | 16.9                                                              |
| "                             | 070915                      | 16.3                                                              |
| "                             | 080805                      | 12.1                                                              |
| "                             | 101045                      | 9.9                                                               |
| 11-8-58, 8:30 a.m.            | 100755                      | 28.4                                                              |
| "                             | 121030                      | 24.2                                                              |
| 11-9-58, 8:30 a.m.            | 100745                      | 38.1                                                              |
| "                             | 121015                      | 32.8                                                              |
| 11-10-58, 8:30 a.m.           | 100830                      | 61.6                                                              |
| "                             | 100915                      | 46.2                                                              |

| <u>24 Hour Sampling<br/>Ending at</u> | <u>Date-Time of<br/>Measurement</u> | <u>Activity, gross beta-gamma<br/>as micro-microcuries per cu. meter</u> |
|---------------------------------------|-------------------------------------|--------------------------------------------------------------------------|
| 11-10-58, 8:30 a.m.                   | 120950                              | 23.8                                                                     |
| "                                     | 130840                              | 24.2                                                                     |
| 11-11-58, 8:30 a.m.                   | 120930                              | 9.8                                                                      |
| "                                     | 130755                              | 8.3                                                                      |
| "                                     | 171030                              | 6.0                                                                      |
| 11-12-58, 9:15 a.m.                   | 120915                              | 66.5                                                                     |
| "                                     | 121000                              | 50.4                                                                     |
| "                                     | 130745                              | 33.9                                                                     |
| "                                     | 171020                              | 22.2                                                                     |
| "                                     | 181015                              | 21.9                                                                     |
| 11-13-58, 8:30 a.m.                   | 130830                              | 71.0                                                                     |
| "                                     | 130915                              | 50.3                                                                     |
| "                                     | 171010                              | 17.8                                                                     |
| "                                     | 181000                              | 15.7                                                                     |
| "                                     | 191045                              | 9.1                                                                      |
| 11-14-58, 8:30 a.m.                   | 171000                              | 21.9                                                                     |
| "                                     | 180945                              | 16.8                                                                     |
| "                                     | 191030                              | 16.6                                                                     |
| 11-15-58, 8:30 a.m.                   | 170940                              | 10.3                                                                     |
| "                                     | 180930                              | 8.0                                                                      |
| "                                     | 191000                              | 7.0                                                                      |
| "                                     | 200955                              | 6.7                                                                      |
| 11-16-58, 8:30 a.m.                   | 170805                              | 8.8                                                                      |
| "                                     | 180840                              | 6.0                                                                      |

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REPORTED BY THEMETROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

## Average Beta Activity in Colorado River

## Water Influent - Softening Plant

| <u>Month</u> | <u>Average<br/>Activity<br/>(<math>\mu</math>mc/liter)</u> |
|--------------|------------------------------------------------------------|
| June         | 7.5                                                        |
| July         | 11.5                                                       |
| August       | 11.2                                                       |
| September    | 11                                                         |
| October      | 31.5                                                       |
| November     | 23                                                         |

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REPORTED BY THE  
METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

TABLE I  
DATA ON GROSS BETA RADIOACTIVITY IN WATER

| Source and Sampling Point   | Date Sampled        | Date of Analysis | Gross Beta $\mu\text{mc/l.}$ |
|-----------------------------|---------------------|------------------|------------------------------|
| <u>Garvey Reservoir</u>     |                     |                  |                              |
| West End                    | 10/24/58            | 11/1/58          | 197 $\pm$ 21                 |
| " "                         | 10/28/58<br>9:10 am | 11/1/58          | 410 $\pm$ 25                 |
| Depth Sample near tower     | 10/28/58<br>9:00 am | 11/1/58          | 47.5 $\pm$ 5.3               |
| Effluent                    | 10/30/58<br>6:45 pm | 11/3/58          | 65.6 $\pm$ 6.7               |
| Surface Sample near tower   | 10/31/58<br>8:00 am | 11/5/58          | 119.4 $\pm$ 7.2              |
| Surface Sample inside tower | 10/31/58<br>8:15 am | 11/5/58          | 34.1 $\pm$ 6.4               |
| Surface Sample west end     | 10/31/58<br>8:10 am | 11/10/58         | 26.5 $\pm$ 6.1               |
| Surface Sample near tower   | 11/3/58             | 11/10/58         | 20.1 $\pm$ 6.0               |
| Surface Sample inside tower | 11/3/58<br>7:45 am  | 11/10/58         | 28.4 $\pm$ 6.1               |
| Surface Sample near tower   | 11/5/58             | 11/11/58         | 23.9 $\pm$ 6.0               |
| Surface Sample inside tower | 11/5/58<br>8:00 am  | 11/11/58         | 22.7 $\pm$ 4.3               |
| Surface Sample inside tower | 11/7/58<br>8:15 am  | 11/14/58         | 17.7 $\pm$ 4.0               |
| Surface Sample near tower   | 11/13/58<br>3:00 pm | 11/18/58         | 26.2 $\pm$ 5.9               |

| Source and Sampling Point     | Date Sampled        | Date of Analysis | Gross Beta $\mu\text{mc/l.}$ |
|-------------------------------|---------------------|------------------|------------------------------|
| <u>Palos Verdes Reservoir</u> |                     |                  |                              |
| Surface                       | 10/24/58<br>7:00 am | 11/1/58          | 56.4 $\pm$ 6.5               |
| Depth                         | 10/26/58<br>3:20 pm | 11/1/58          | 79.8 $\pm$ 6.8               |
| Surface                       | 10/28/58<br>3:20 pm | 11/3/58          | 30.7 $\pm$ 3.1               |
| "                             | 10/31/58<br>7:40 am | 11/4/58          | 37.1 $\pm$ 8.9               |
| "                             | 11/2/58<br>7:50 am  | 11/10/58         | 53.9 $\pm$ 6.4               |
| "                             | 11/4/58<br>7:05 am  | 11/11/58         | 46.5 $\pm$ 6.3               |
| "                             | 11/6/58<br>7:10 am  | 11/14/58         | 49.5 $\pm$ 6.3               |
| "                             | 11/8/58<br>7:30 am  | 11/14/58         | 25.9 $\pm$ 5.9               |
| "                             | 11/10/58<br>7:00 am | 11/14/58         | 24.1 $\pm$ 5.9               |
| "                             | 11/12/58<br>7:00 am | 11/18/58         | 35.5 $\pm$ 6.1               |

| <u>Source and Sampling Point</u> | <u>Date Sampled</u> | <u>Date of Analysis</u> | <u>Gross Beta <math>\mu\text{mc/l.}</math></u> |
|----------------------------------|---------------------|-------------------------|------------------------------------------------|
| <u>Garvey Reservoir</u>          |                     |                         |                                                |
| Surface Sample inside tower      | 11/13/58<br>3:00 pm | 11/18/58                | 26.7 $\pm$ 5.9                                 |
| Orange County Res. Outlet        | 11/1/58<br>7:30 am  | 11/8/58                 | 25.1 $\pm$ 6.0                                 |
| Corona Del Mar Res. Outlet       | 11/1/58             | 11/8/58                 | 19.1 $\pm$ 8.3                                 |

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TABLE II

| <u>Source and Sampling Point</u> | <u>Date Sampled</u> | <u>Date of Analysis</u> | <u>Gross Beta <math>\mu\text{mc/l.}</math></u> |
|----------------------------------|---------------------|-------------------------|------------------------------------------------|
| <u>Decay Measurements:</u>       |                     |                         |                                                |
| Garvey Reservoir West End        | 10/28/58            | 11/1/58                 | 410                                            |
|                                  |                     | 4:00 pm                 |                                                |
|                                  |                     | 11/4/58                 | 171                                            |
|                                  |                     | 9:00 am                 |                                                |
|                                  |                     | 11/6/58                 | 150                                            |
|                                  |                     | 10:30 am                |                                                |
|                                  |                     | 11/11/58                | 123                                            |
|                                  |                     | 2:00 pm                 |                                                |
| Palos Verdes Res. Surface        | 10/24/58            | 11/19/58                | 98.8                                           |
|                                  |                     | 1:00 pm                 |                                                |
|                                  |                     | 11/26/58                | 75.3                                           |
|                                  |                     | 12:30 pm                |                                                |
|                                  |                     | 11/1/58                 | 56.4                                           |
|                                  |                     | 11/19/58                | 30.1                                           |
|                                  |                     | 11/25/58                | 20.2                                           |
|                                  |                     |                         |                                                |
| Palos Verdes Res. Depth Sample   | 10/26/58            | 11/1/58                 | 79.8                                           |
|                                  |                     | 11/4/58                 | 66.0                                           |
|                                  |                     | 11/12/58                | 38.8                                           |
|                                  |                     | 11/19/58                | 44.9                                           |
|                                  |                     | 11/25/58                | 27.2                                           |

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TABLE III

| Source and Sampling Point                                                     | Date Sampled | Date of Analysis | Gross Beta $\mu\text{mc/l.}$ |
|-------------------------------------------------------------------------------|--------------|------------------|------------------------------|
| Influent -<br>F. E. Weymouth<br>Softening and<br>Filtration Plant<br>La Verne | 9/29/58      | 10/10/58         | 25.8 $\pm$ 4.8               |
|                                                                               | 9/30/58      | 10/10/58         | 26.4 $\pm$ 4.8               |
|                                                                               | 10/2/58      | 10/10/58         | 28.6 $\pm$ 8.3               |
|                                                                               | 10/29/58     | 11/1/58          | 48.7 $\pm$ 6.4               |
|                                                                               | 10/30/58     | 11/3/58          | 96.9 $\pm$ 8.1               |
|                                                                               | 10/31/58     | 11/3/58          | 42.0 $\pm$ 5.3               |
|                                                                               | 11/1/58      | 11/4/58          | 36.9 $\pm$ 6.3               |
|                                                                               | 11/3/58      | 11/8/58          | 53.0 $\pm$ 6.6               |
|                                                                               | 11/4/58      | 11/8/58          | 48.5 $\pm$ 5.2               |
|                                                                               | 11/5/58      | 11/12/58         | 28.3 $\pm$ 6.0               |
|                                                                               | 11/6/58      | 11/13/58         | 32.6 $\pm$ 6.1               |
|                                                                               | 11/7/58      | 11/13/58         | 30.7 $\pm$ 6.0               |
|                                                                               | 11/10/58     | 11/13/58         | 24.0 $\pm$ 4.9               |
|                                                                               | 11/11/58     | 11/14/58         | 20.2 $\pm$ 5.9               |
|                                                                               | 11/12/58     | 11/17/58         | 24.4 $\pm$ 6.0               |

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TABLE IV

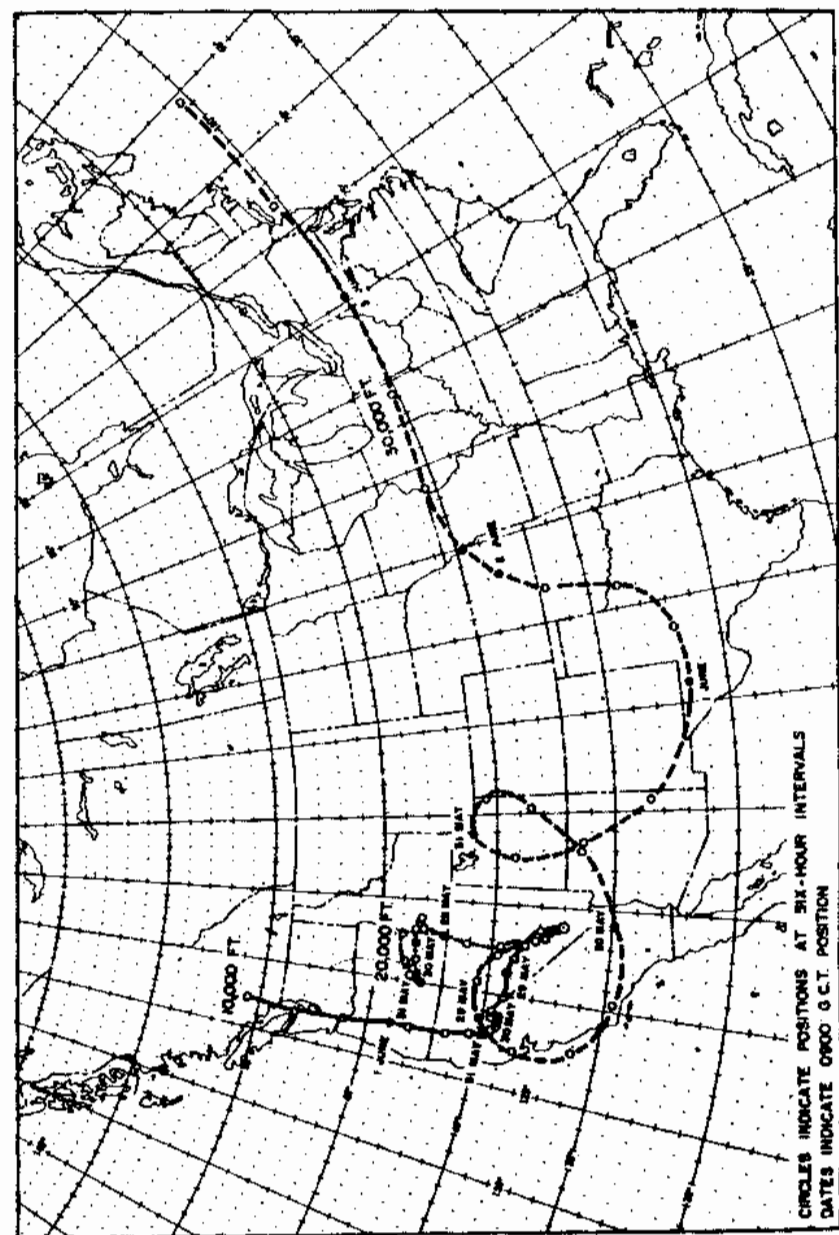
| Source and Sampling Point                                                     | Date Sampled | Date of Analysis | Gross Beta $\mu\text{mc/l.}$ |
|-------------------------------------------------------------------------------|--------------|------------------|------------------------------|
| Effluent -<br>F. E. Weymouth<br>Softening and<br>Filtration Plant<br>La Verne | 10/28/58     | 11/1/58          | 36.9 $\pm$ 6.2               |
|                                                                               | 10/29/58     | 11/3/58          | 22.8 $\pm$ 5.1               |
|                                                                               | 10/30/58     | 11/3/58          | 28.4 $\pm$ 5.1               |
|                                                                               | 10/31/58     | 11/4/58          | 22.2 $\pm$ 5.0               |
|                                                                               | 11/2/58      | 11/8/58          | 28.5 $\pm$ 6.1               |
|                                                                               | 11/3/58      | 11/8/58          | 43.3 $\pm$ 6.3               |
|                                                                               | 11/5/58      | 11/12/58         | 32.7 $\pm$ 6.1               |
|                                                                               | 11/6/58      | 11/13/58         | 29.4 $\pm$ 6.0               |
|                                                                               | 11/9/58      | 11/13/58         | 20.0 $\pm$ 4.8               |
|                                                                               | 11/10/58     | 11/14/58         | 18.1 $\pm$ 4.3               |
|                                                                               | 11/11/58     | 11/17/58         | 23.8 $\pm$ 6.0               |

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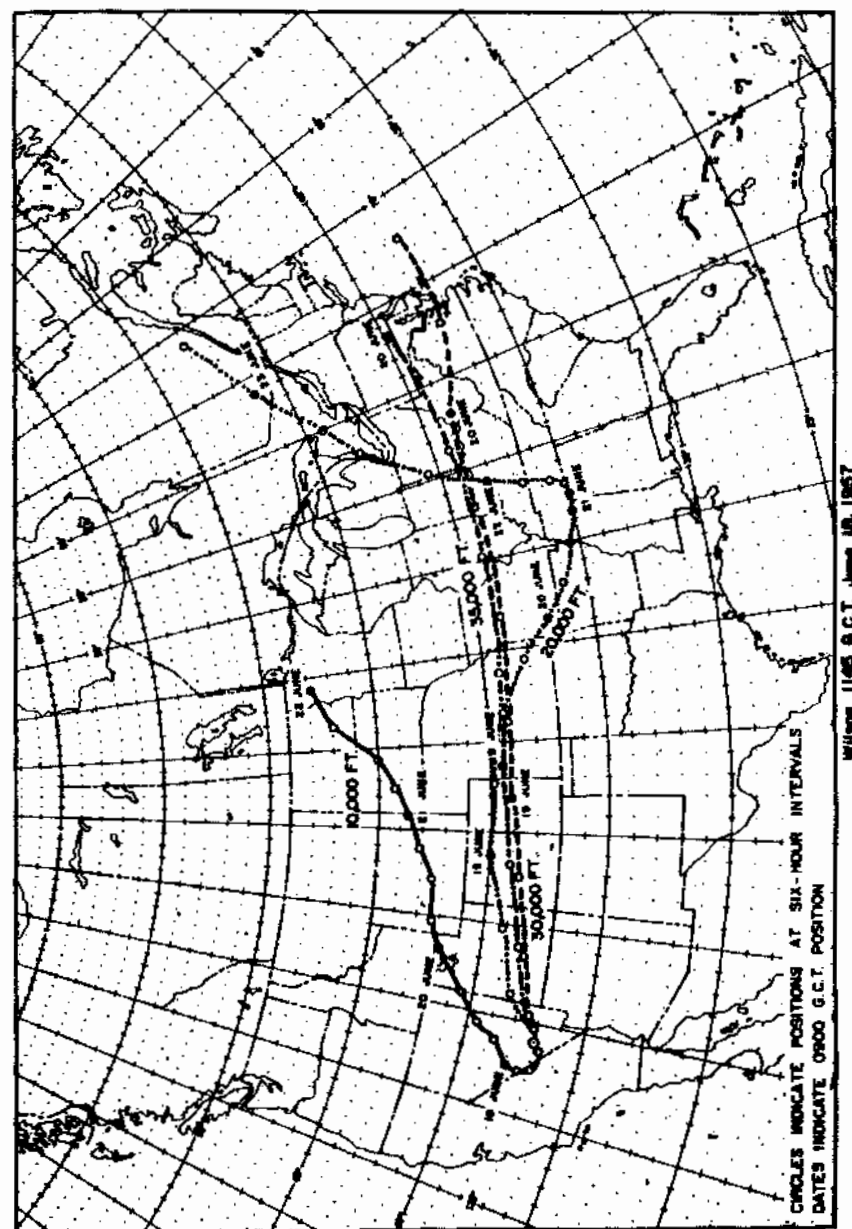
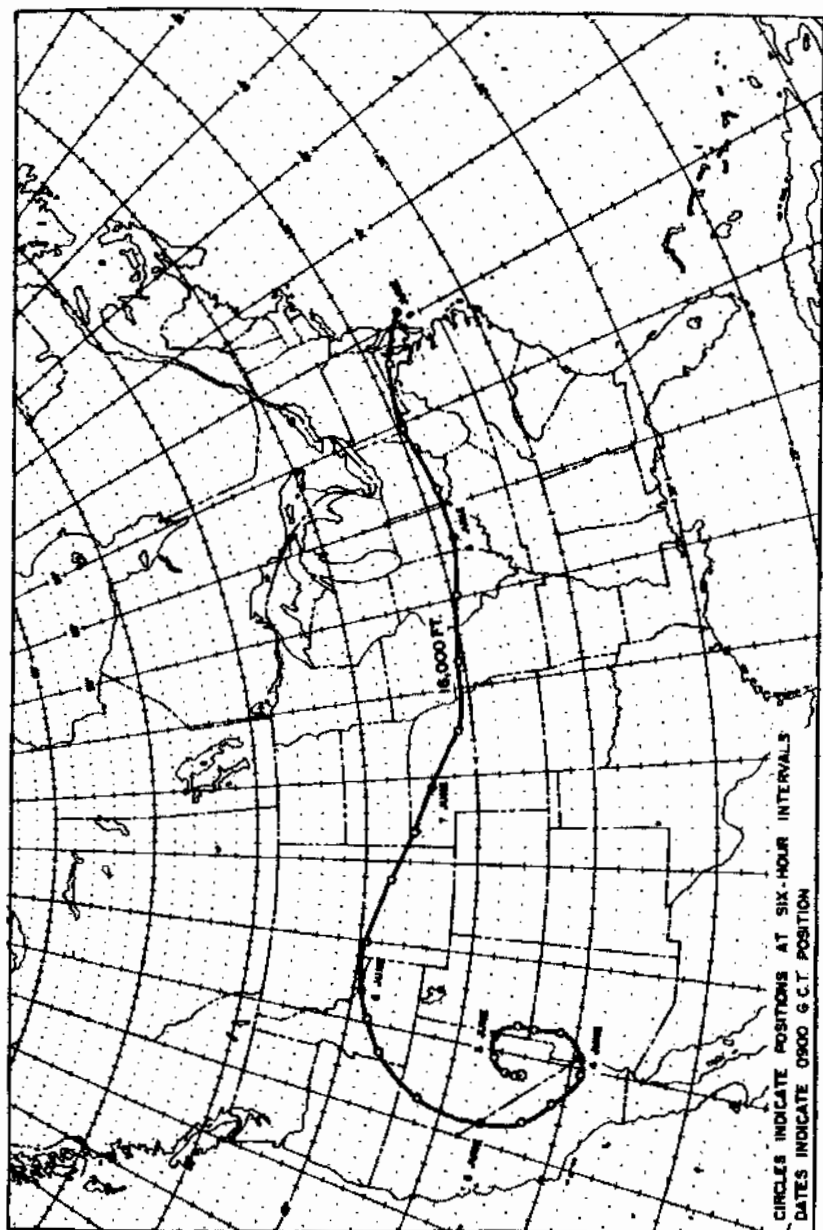
TABLE V

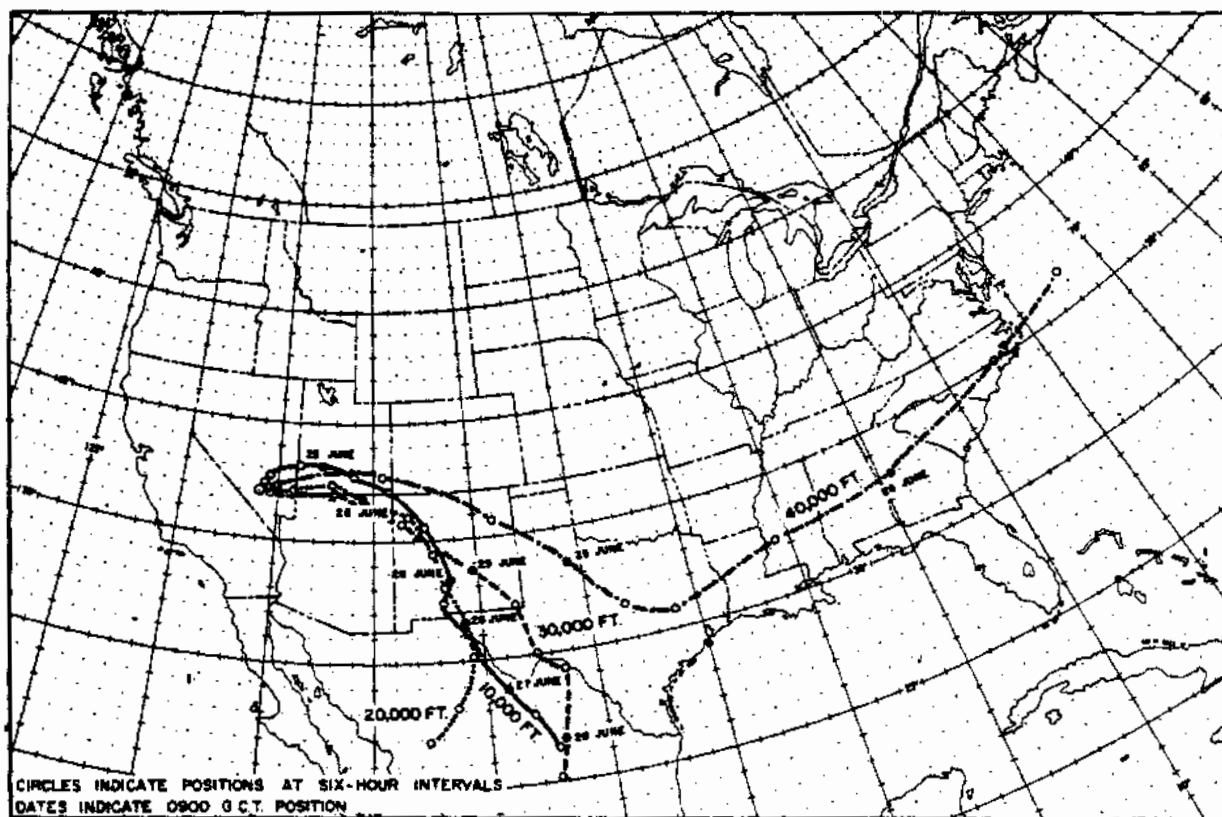
| Source and<br>Sampling Point                                      | Date<br>Sampled | Date of<br>Analysis | Gross Beta<br>$\mu\text{C/l.}$ |
|-------------------------------------------------------------------|-----------------|---------------------|--------------------------------|
| <u>Decay Measurements:</u>                                        |                 |                     |                                |
| Influent -<br>F. E. Weymouth<br>Softening and<br>Filtration Plant | 10/29/58        | 11/1/58             | 48.7                           |
|                                                                   |                 | 9:00 am             |                                |
|                                                                   |                 | 11/5/58             | 37.8                           |
|                                                                   |                 | 10:00 am            |                                |
|                                                                   |                 | 11/18/58            | 39.2                           |
|                                                                   |                 | 2:00 pm             |                                |
| Influent -<br>F. E. Weymouth<br>Softening and<br>Filtration Plant | 10/30/58        | 11/3/58             | 96.9                           |
|                                                                   |                 | 8:30 am             |                                |
|                                                                   |                 | 11/4/58             | 86.7                           |
|                                                                   |                 | 11:30 am            |                                |
|                                                                   |                 | 11/12/58            | 71.1                           |
|                                                                   |                 | 10:30 am            |                                |
|                                                                   |                 | 11/20/58            | 52.2                           |
|                                                                   |                 | 12:30 pm            |                                |
| Effluent -<br>F. E. Weymouth<br>Softening and<br>Filtration Plant | 10/28/58        | 11/1/58             | 36.9                           |
|                                                                   |                 | 10:00 am            |                                |
|                                                                   |                 | 11/5/58             | 30.3                           |
|                                                                   |                 | 12:05 pm            |                                |
|                                                                   |                 | 11/19/58            | 25.6                           |
|                                                                   |                 | 8:15 am             |                                |
|                                                                   |                 | 11/25/58            | 11.9                           |
|                                                                   |                 | 2:30 pm             |                                |

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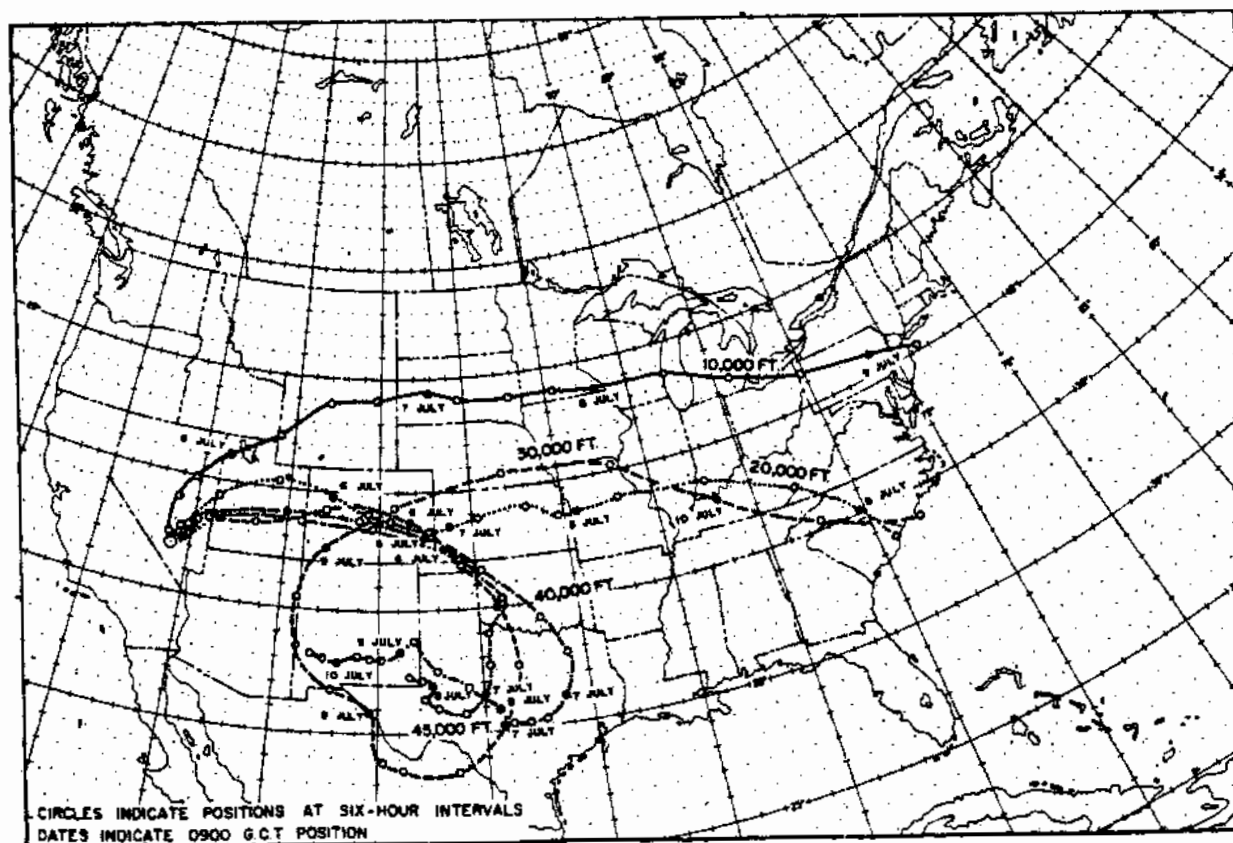


Boltzmann, 1155 G.C.T. May 28, 1957

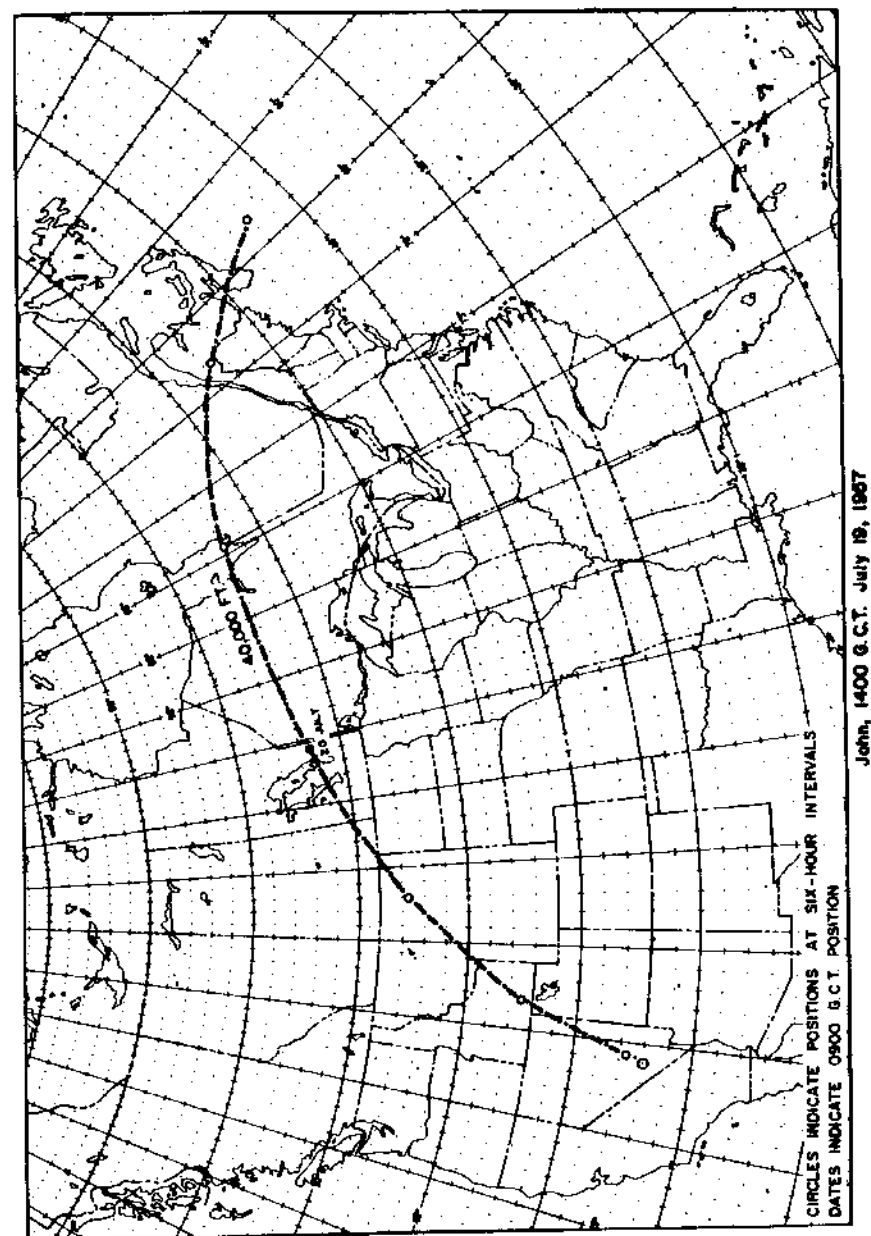
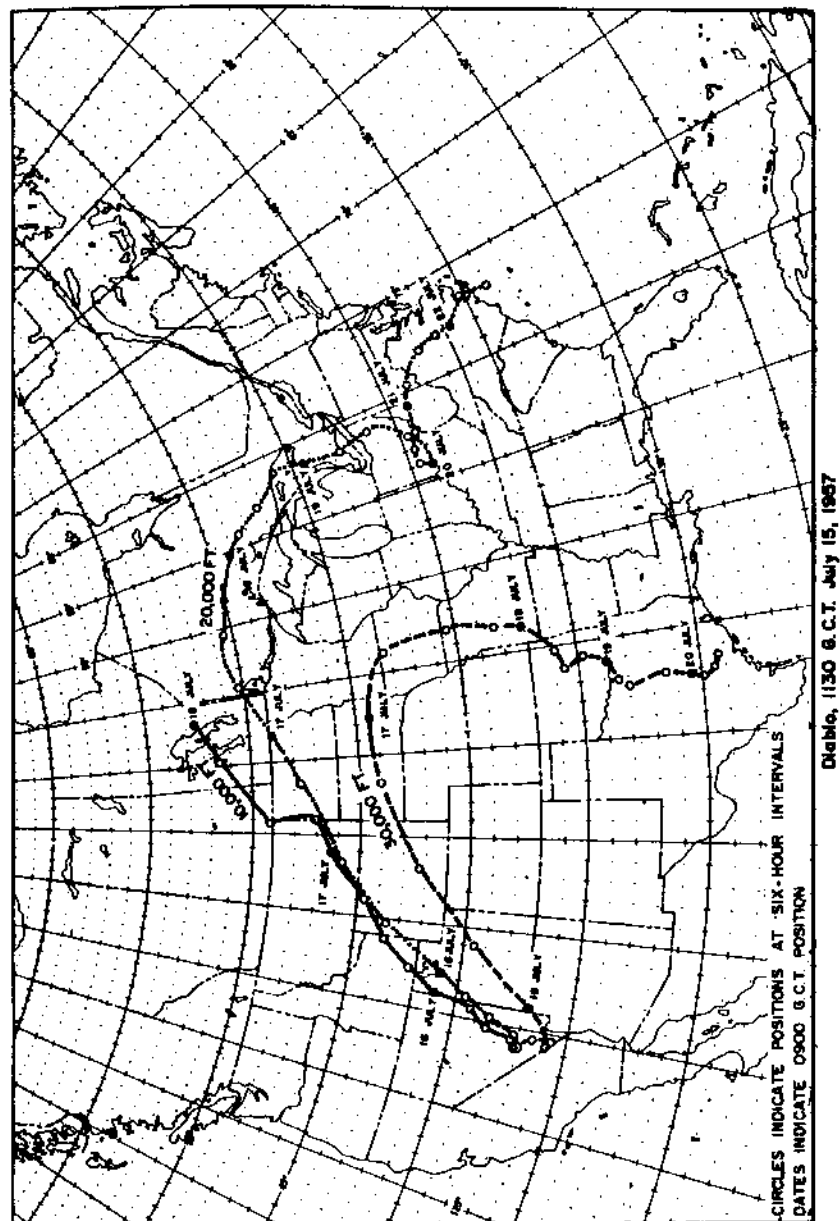


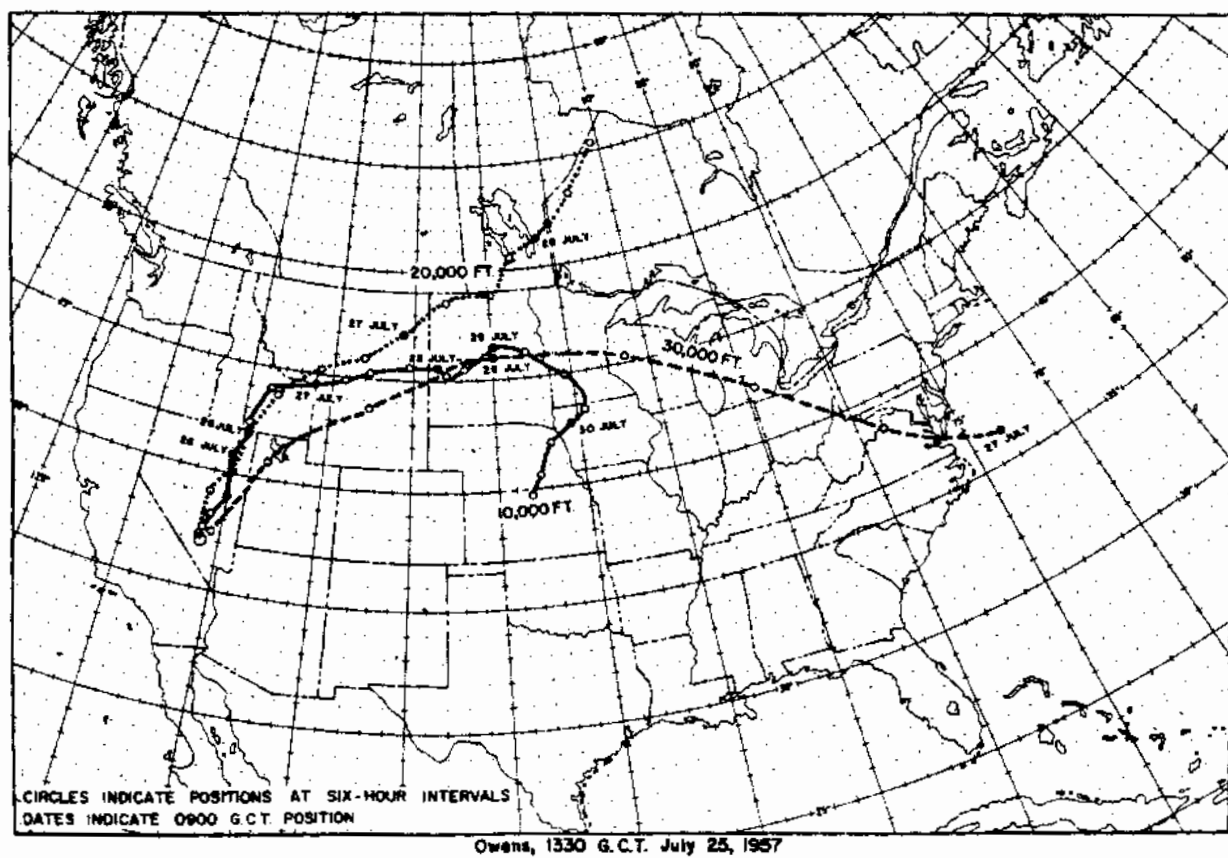
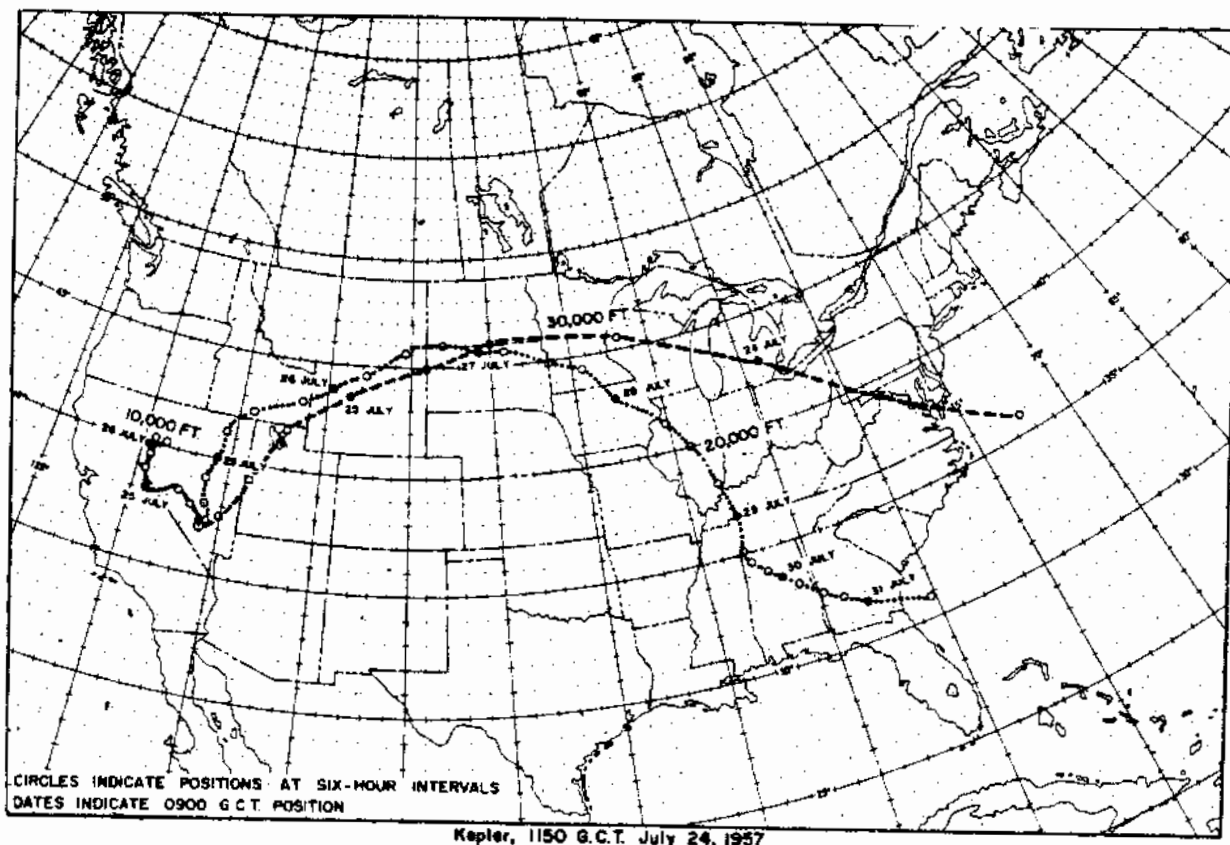


Priscilla, 1330 G.C.T. June 24, 1957

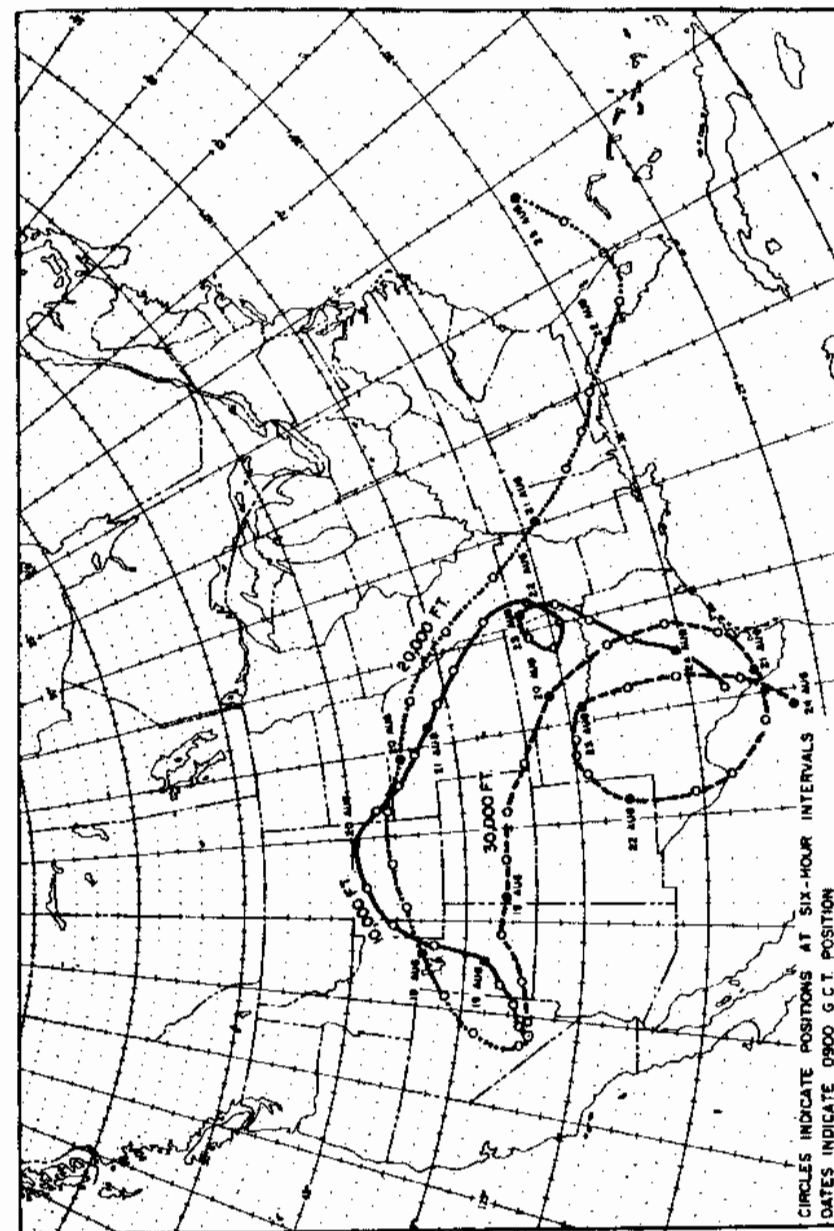
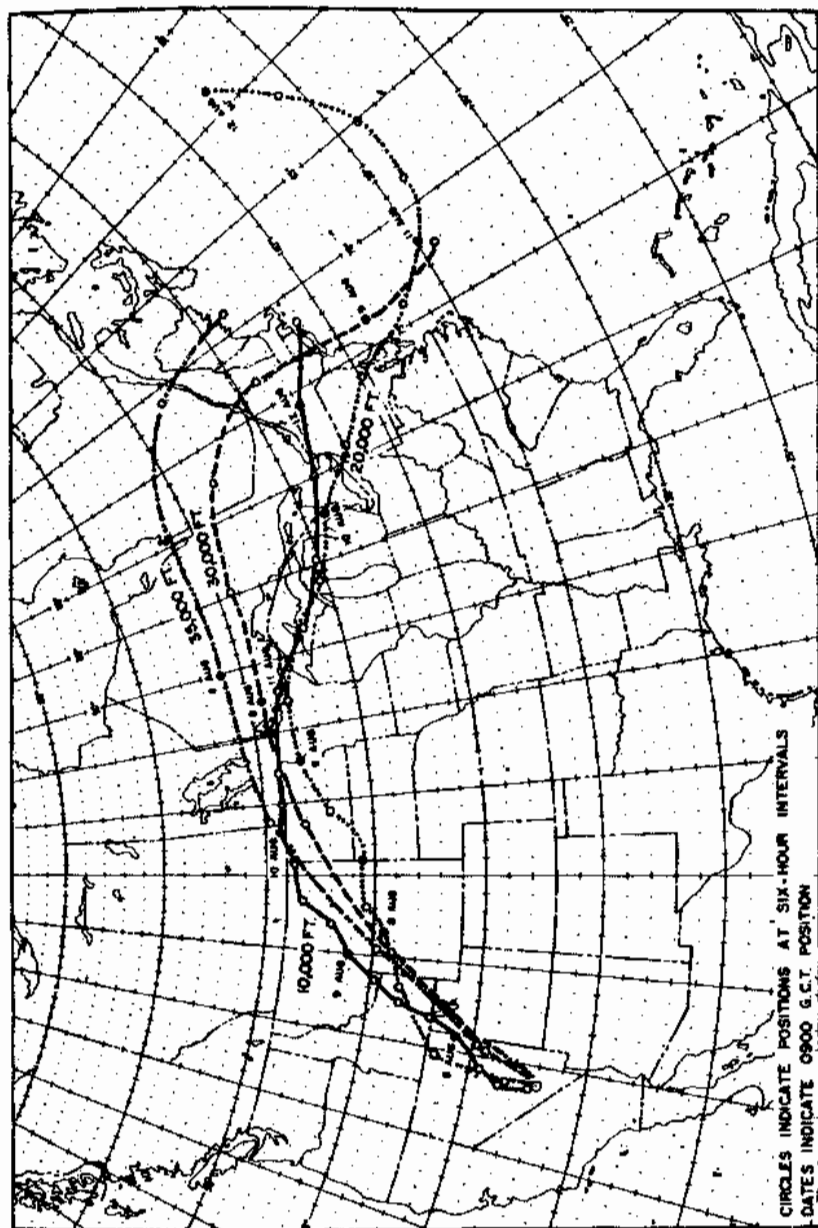


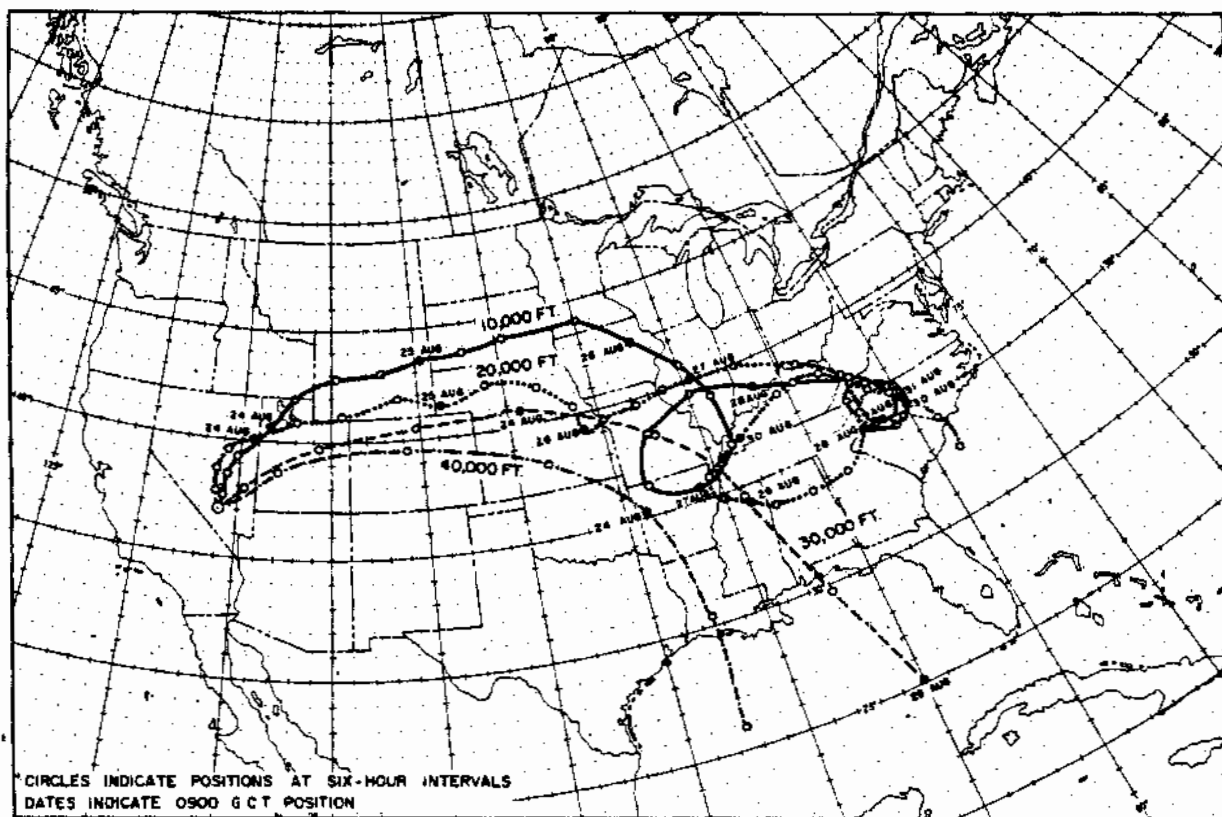
Head, 1140 G.C.T. July 5, 1957



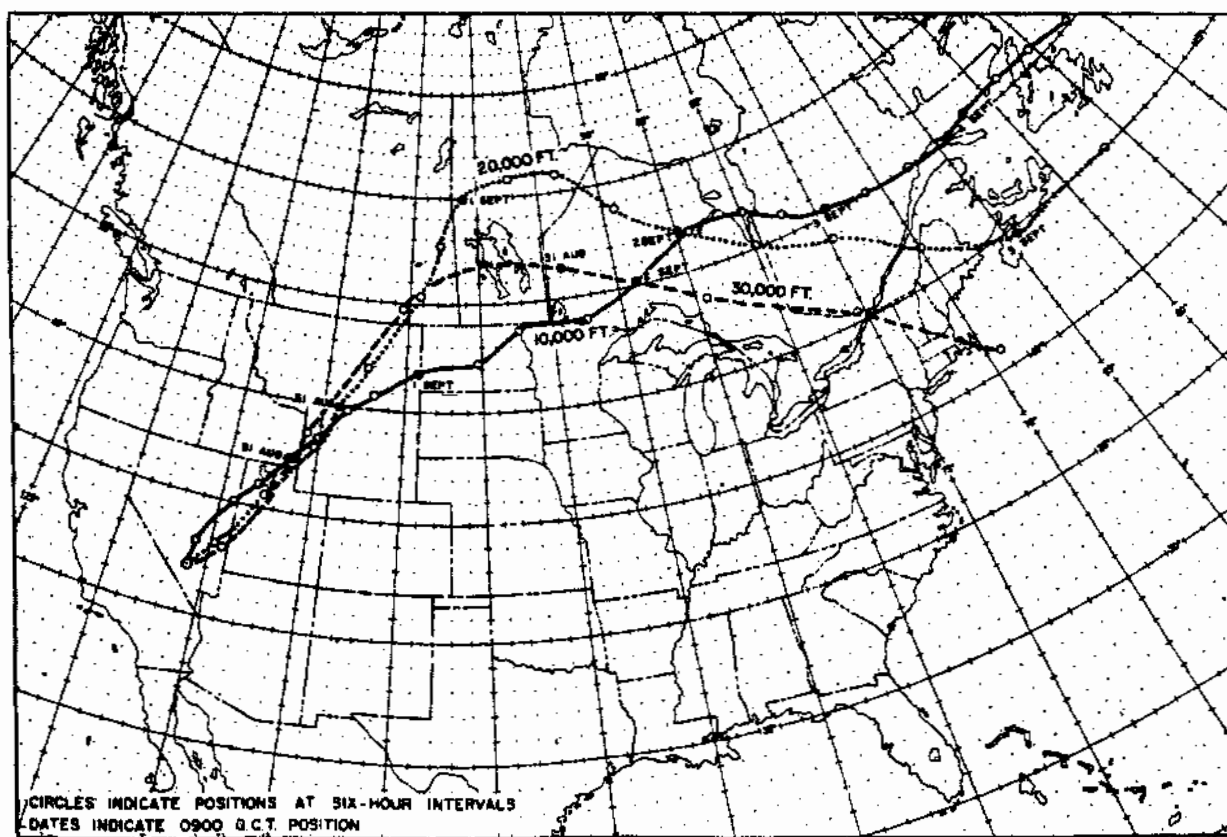




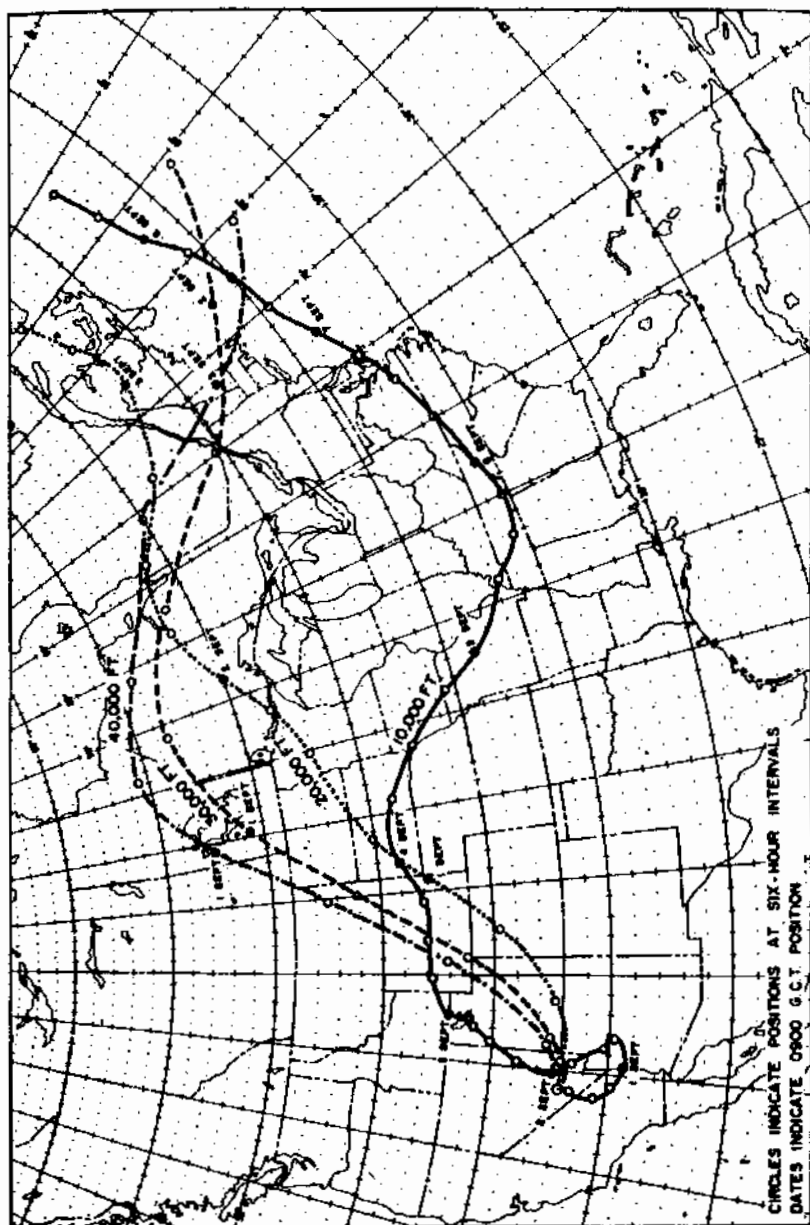




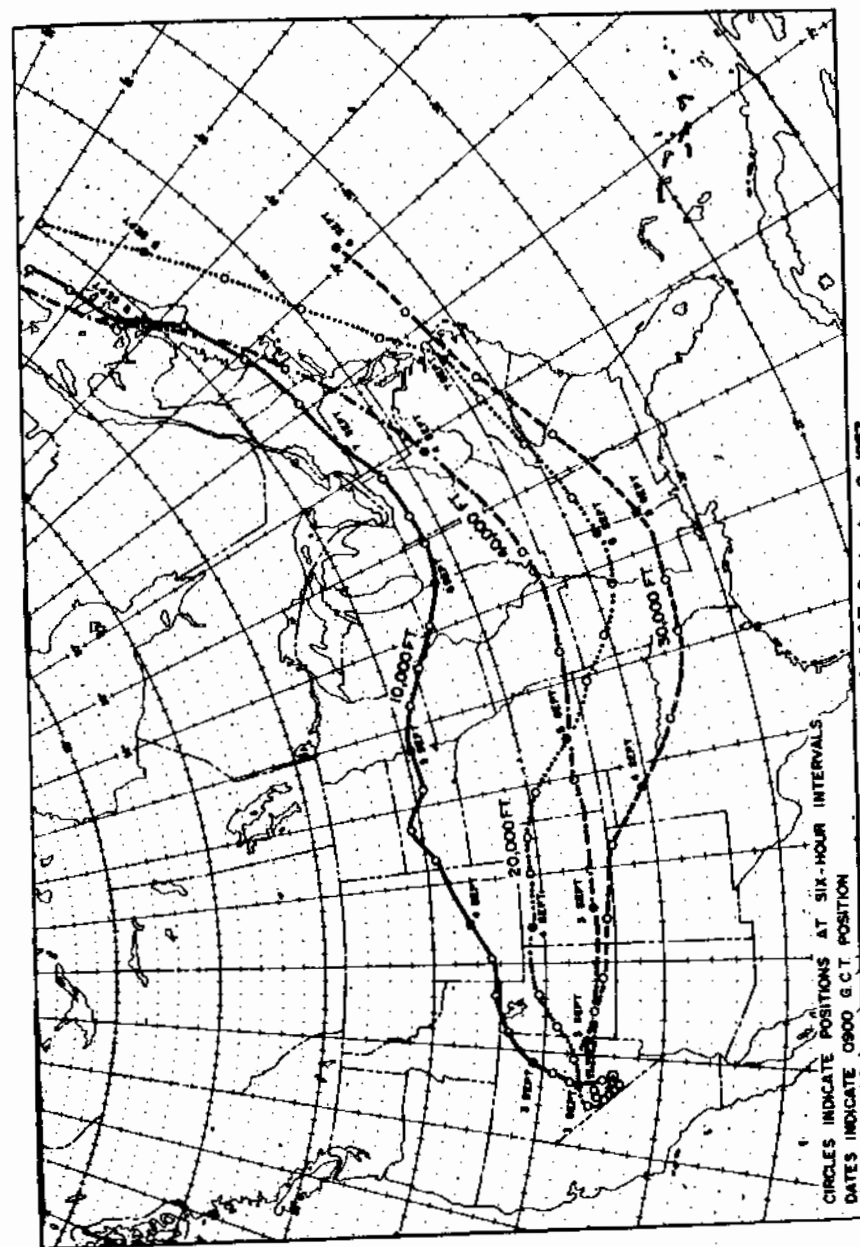
Doppler, 1230 G.C.T. August 23, 1957



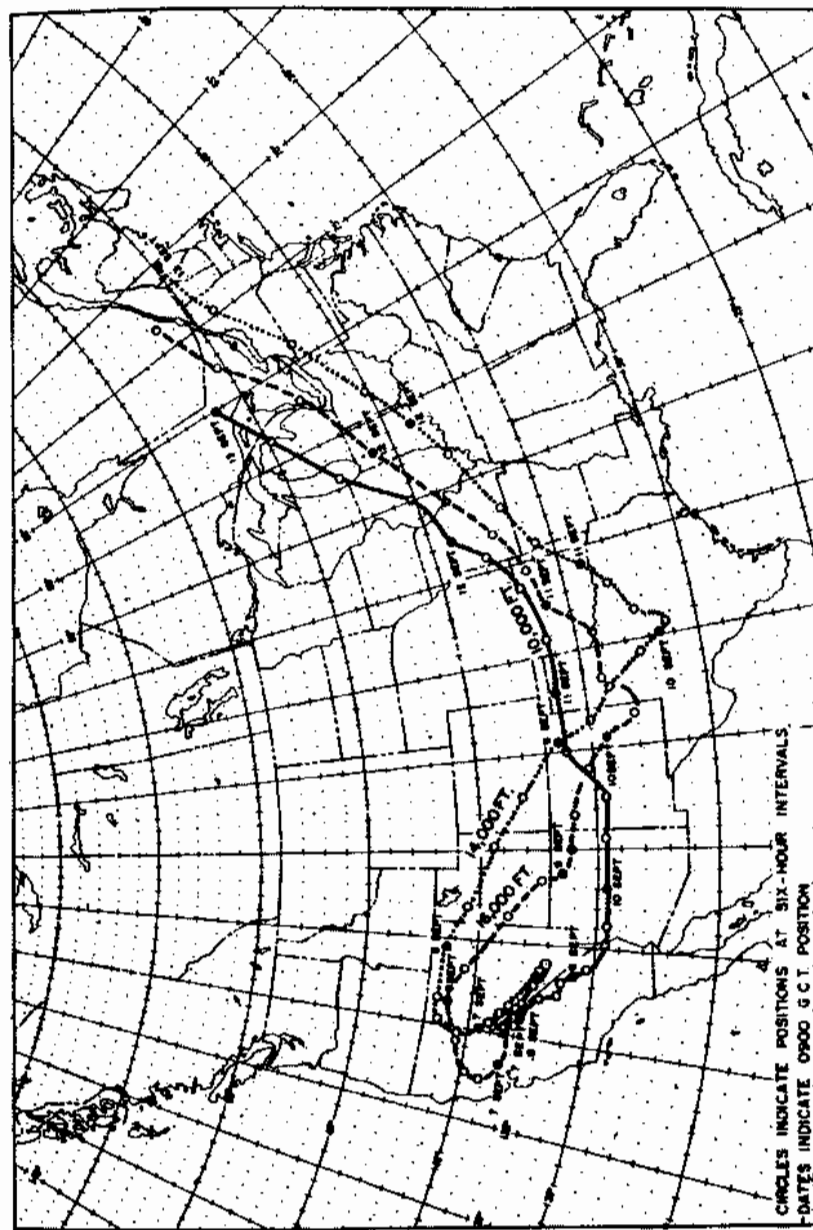
Franklin Prime, 1240 G.C.T. August 30, 1957



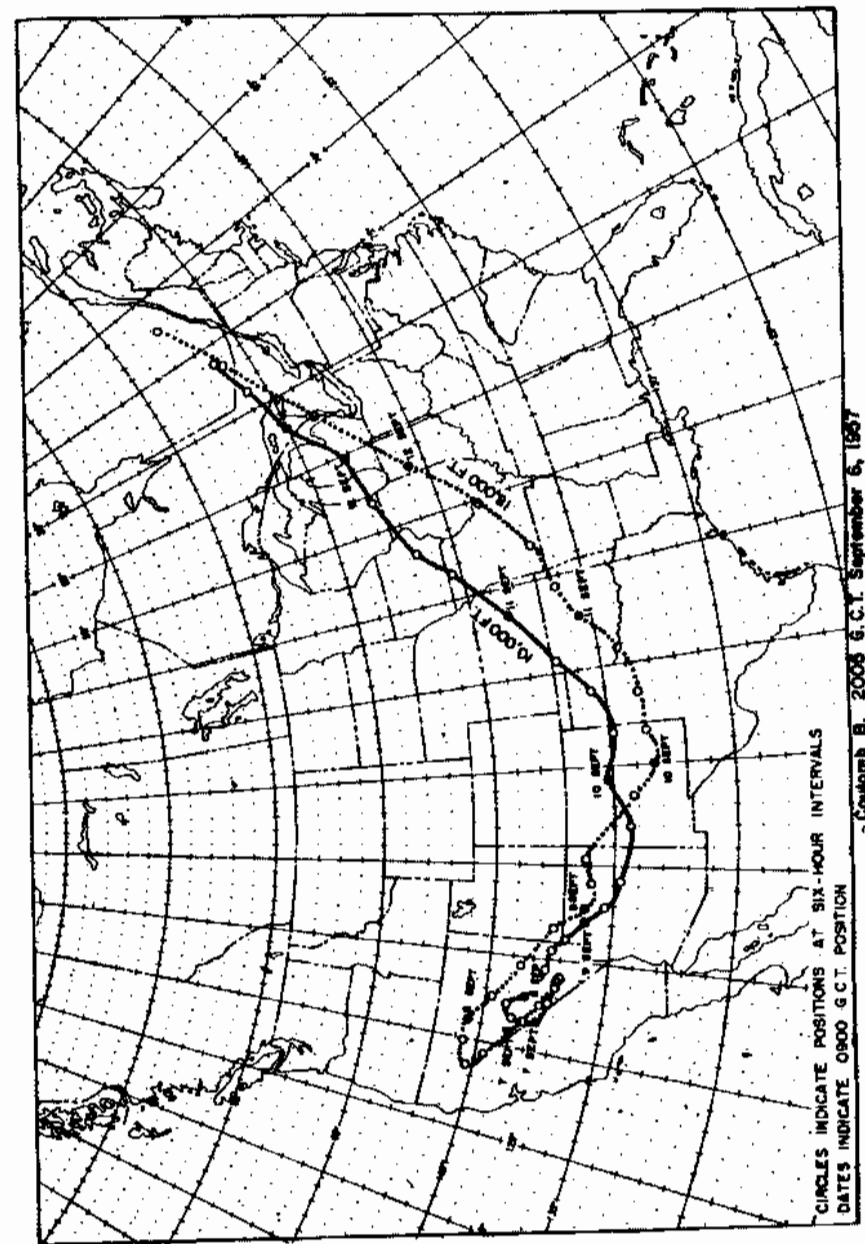
Smoky, 1230 G.C.T. August 31, 1957



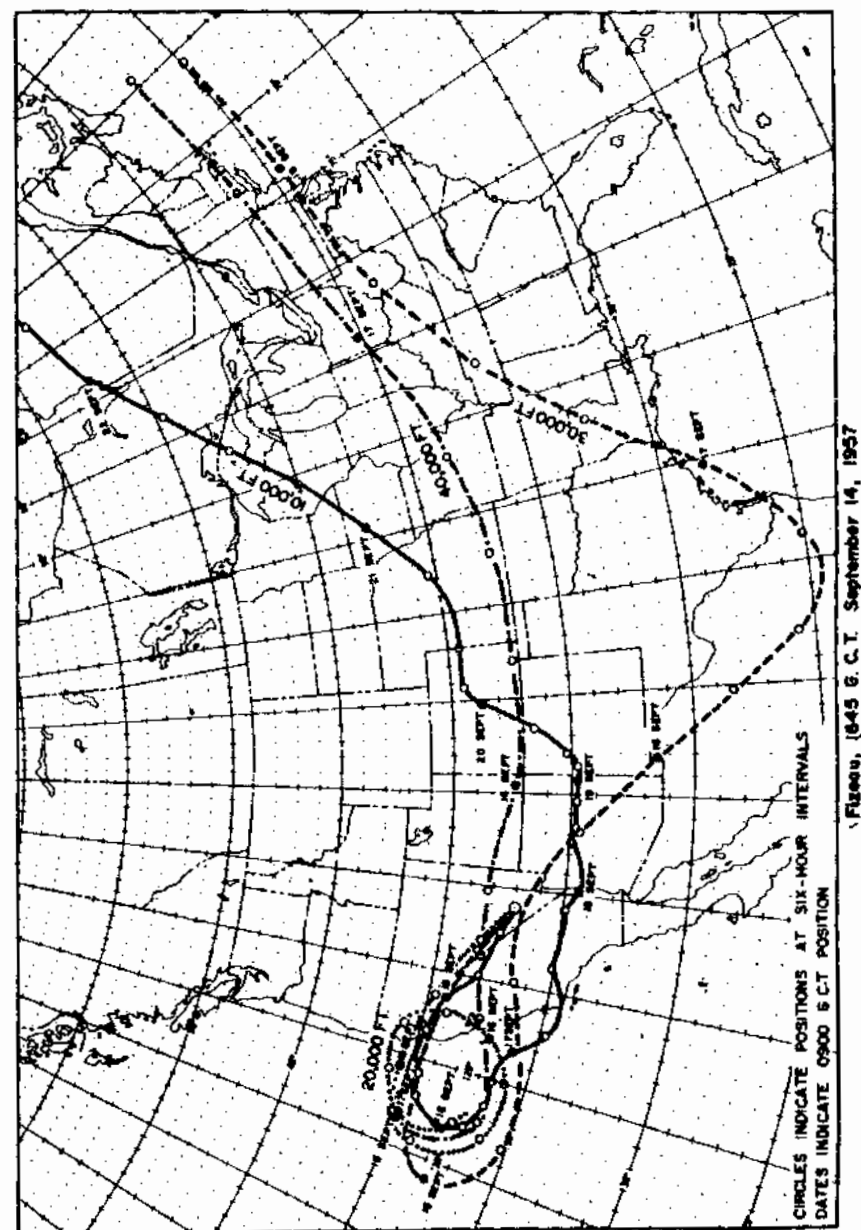
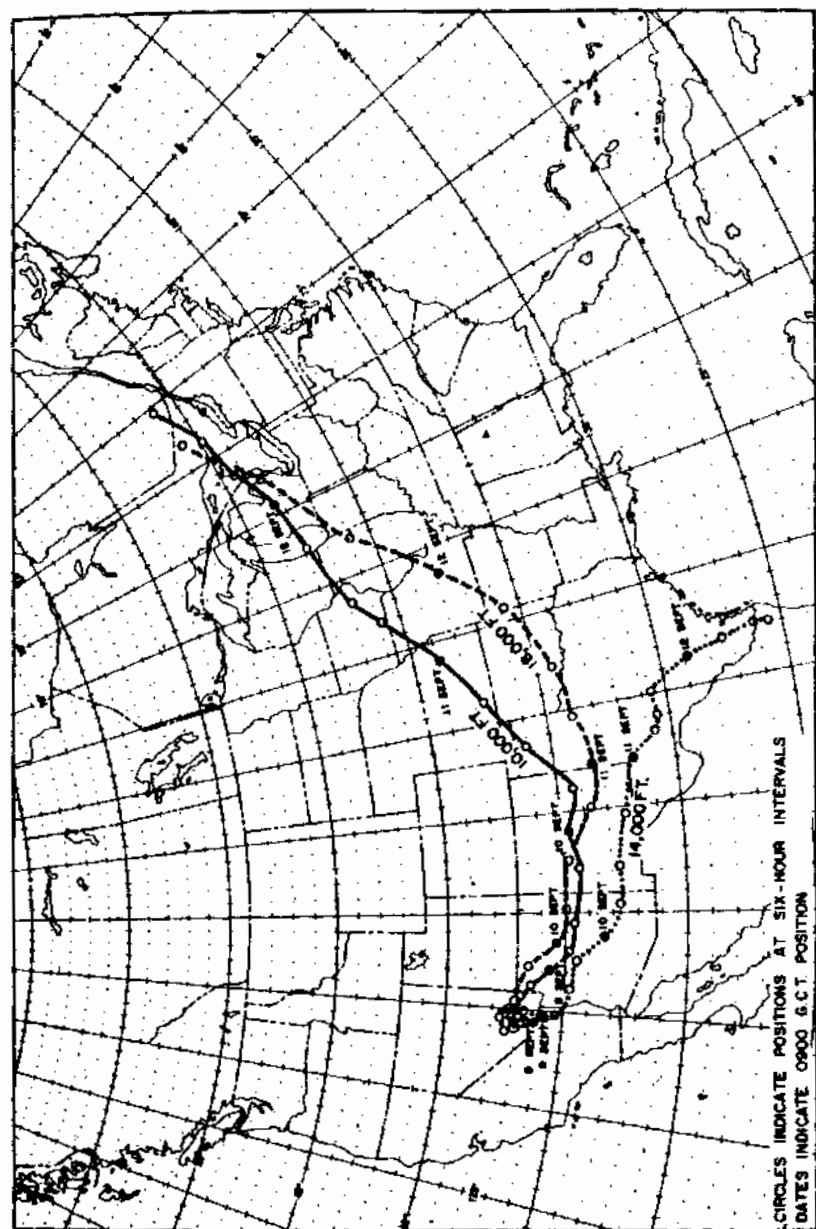
Gallies, 1240 G.C.T. September 2, 1957

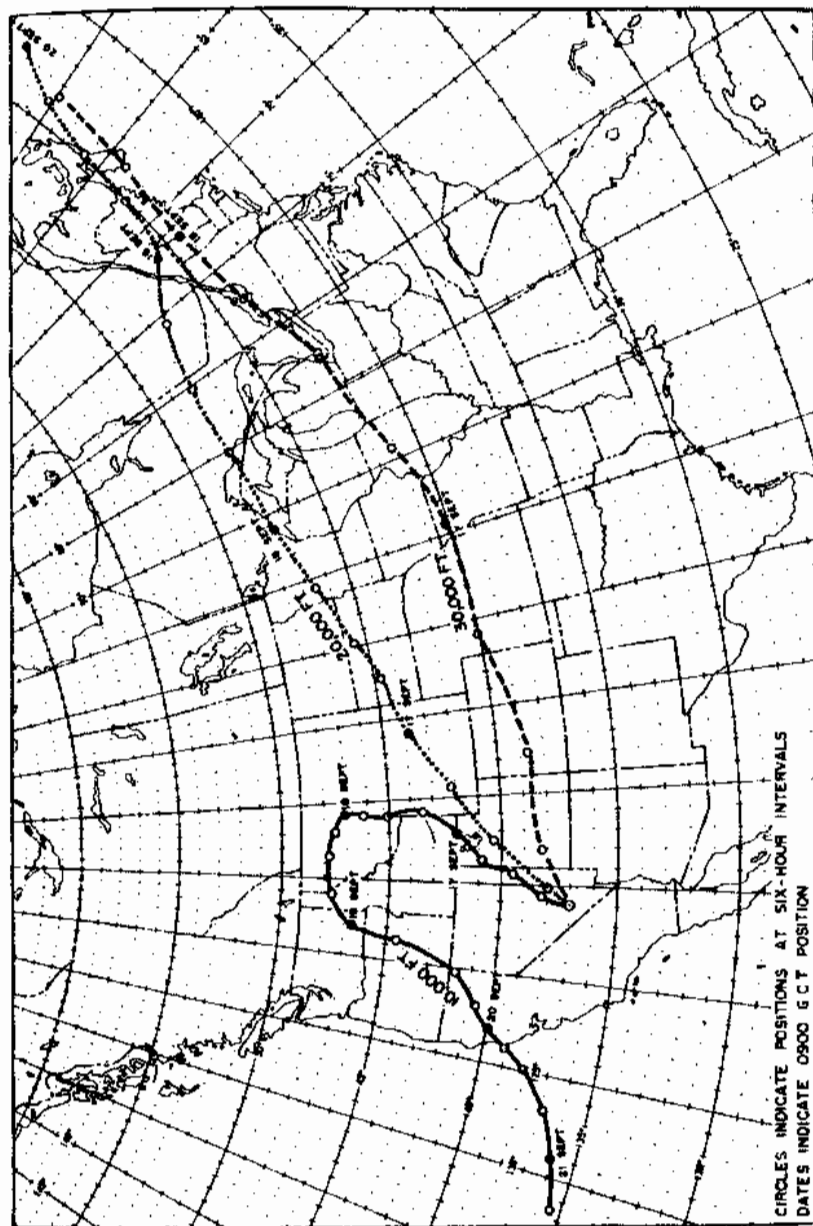


Wheeler, 1245 G.C.T. September 6, 1957

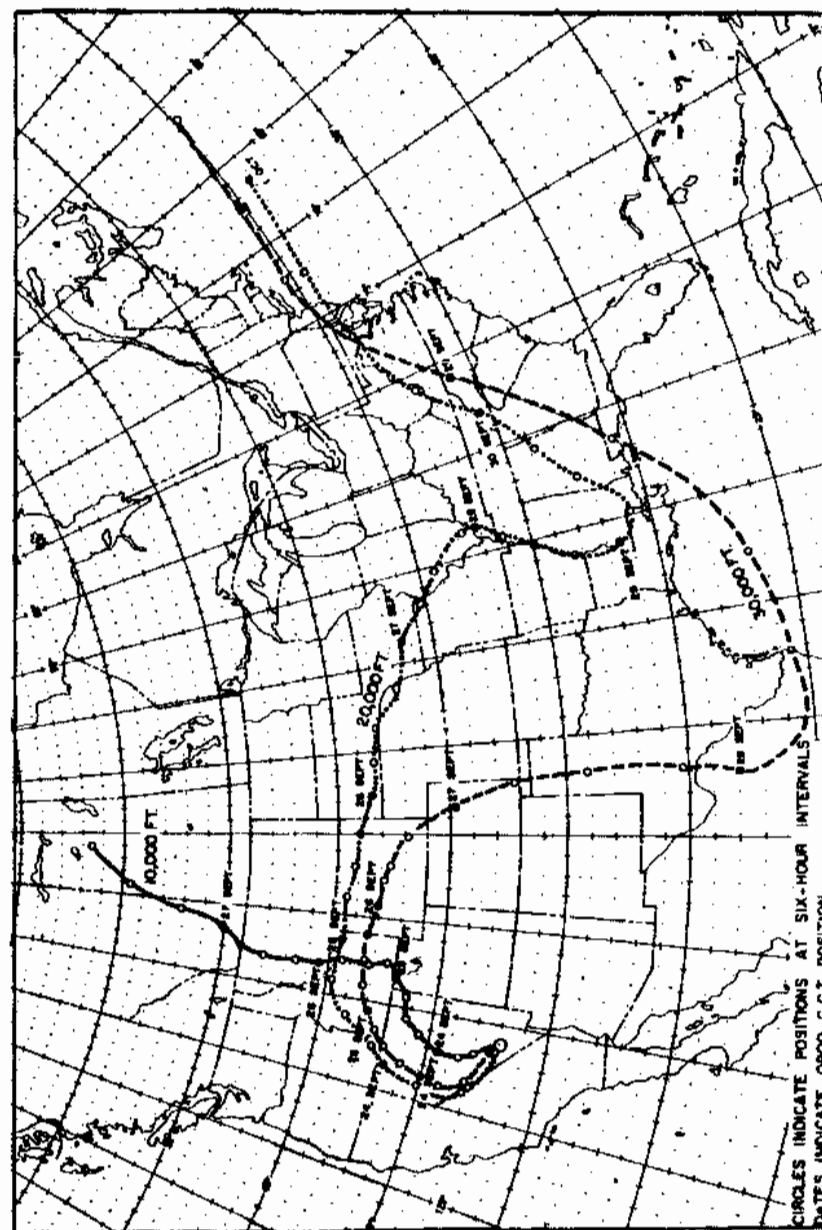


Columbia B, 2008 G.C.T. September 6, 1957



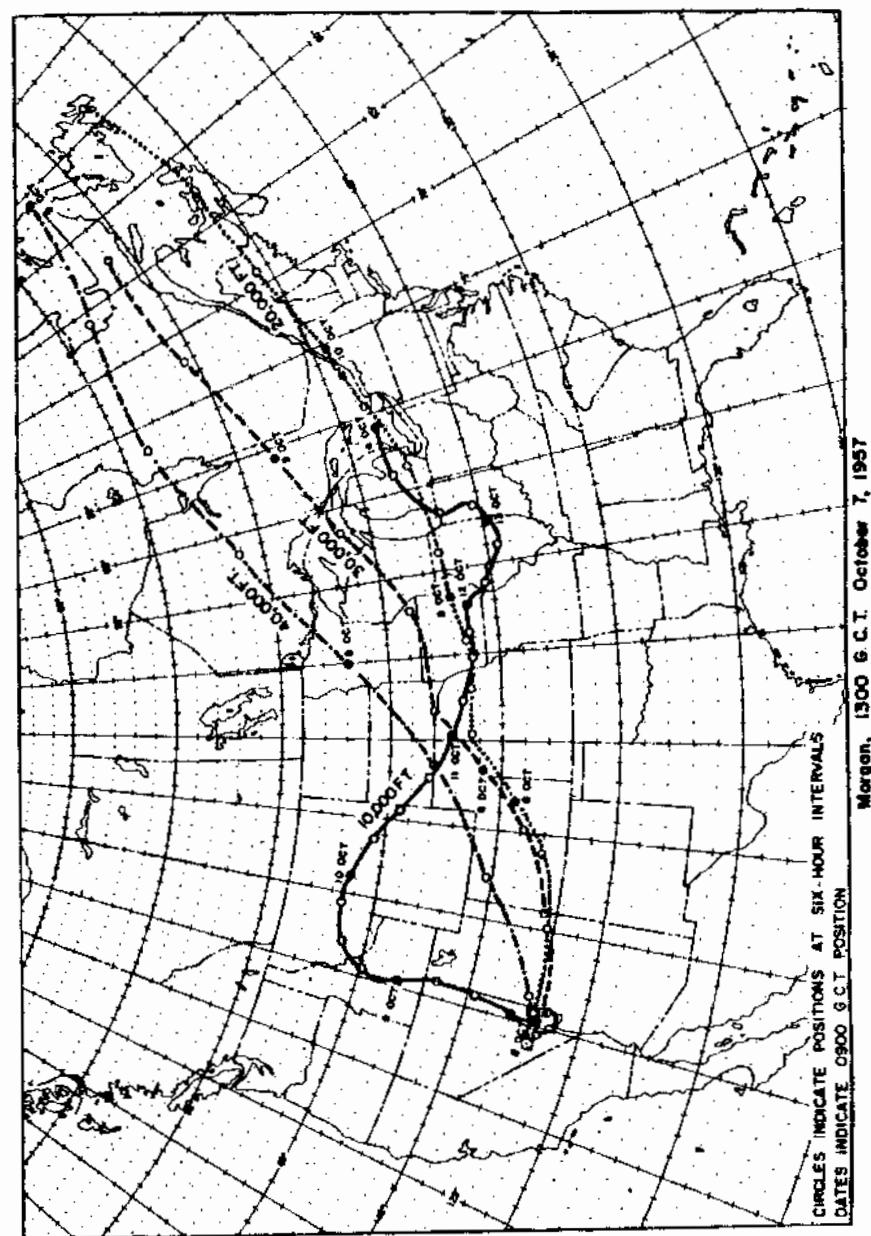
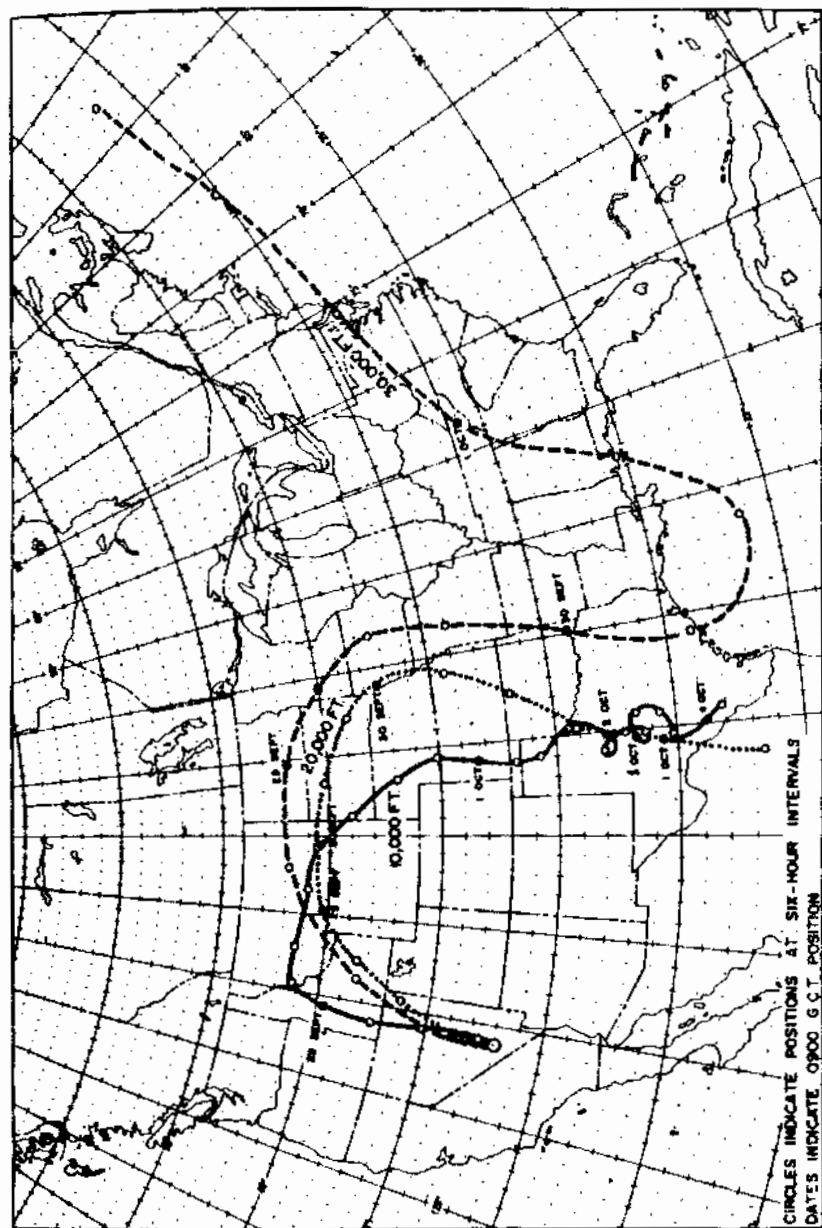


Newton, 1250 G.C.T. September 16, 1957



Whitney, 1230 G.C.T. September 23, 1957





## APPENDIX B

## "HOT SPOT" PROBLEM AND STRONTIUM 90 IN FOODS

CONGRESS OF THE UNITED STATES,  
JOINT COMMITTEE ON ATOMIC ENERGY,  
May 18, 1959.

Gen. A. R. LUEDECKE,  
General Manager,  
U.S. Atomic Energy Commission,  
Washington, D.C.

DEAR GENERAL LUEDECKE: In connection with the recent public hearings by the Special Subcommittee on Radiation on fallout from nuclear weapons tests, I believe that there were two areas which were not sufficiently covered during the course of the hearings. These are the so-called local hot spot problem, and the problem of short-lived isotopes whose importance may be greater than once thought because of the faster rate of fallout from the stratosphere.

It had been our understanding that the hot spot area problems would receive comprehensive treatment in the hearings. Thus, our outline specifically designated it for discussion in the general review of developments since 1957 with the idea that it would be further discussed at appropriate points by AEC and other witnesses. It is true that the hot spot problem was touched upon at various points, but it was not dealt with in any thorough scientific manner. I am sure that much data was submitted bearing on the problem, but again it was not treated as a subject matter of specific concern.

It would therefore be appreciated if the Commission would provide a statement describing and evaluating the hot spot problem. Such a statement might cover among other things: (a) why we have a hot spot problem; (b) the extent of the hot spot problem, i.e., the areas involved, and the radiation levels (both external and strontium) in these areas compared to averages for the United States and worldwide; (c) the implications of these hot spot areas from the standpoint of maximum permissible exposure levels, both as to testing to date, and possible future testing, using guidelines established by the seminar on implications of testing.

The problem of short-lived isotopes also appears to require further identification and evaluation. Although the subcommittee's outline did not identify the problem, its implications were noted in discussions on the more rapid rate of global fallout. Several papers were submitted on it.

It would be appreciated if the Commission could supply the subcommittee with a supplementary statement on these two matters so that our fallout hearing record may be complete on these two subject areas.

The Commission's cooperation in this matter is appreciated.

Sincerely yours,

CHET HOLIFIELD,  
Chairman, Special Subcommittee on Radiation.

ATOMIC ENERGY COMMISSION,  
Washington, D.C., June 2, 1959.

HON. CHET HOLIFIELD,  
Chairman, Special Subcommittee on Radiation, Joint Committee on Atomic Energy, Congress of the United States.

DEAR MR. HOLIFIELD: In reply to the request contained in your letter of May 18, 1959, we have prepared for inclusion in the record of the recent fallout hearings the enclosed supplementary statements on (1) the so-called hot spot problems and (2) (see vol. 2, p. 1806) the problem of short-lived radioisotopes in worldwide

fallout. We expect to give these questions further consideration in our future studies.

If we can be of further assistance, please let us know.

Sincerely yours,

A. R. LUEDECKE, General Manager.

## THE HOT SPOT PROBLEM AND WORLDWIDE FALLOUT

(Submitted by AEC)

What we are concerned with here are areas the size of many square miles, often as large as many counties and even as large as several States, over which a rainstorm has dumped radioactive debris which had become incorporated in it either as tropospheric debris from some quite recent weapons tests in Nevada or from some U.S.S.R. test. It is less likely that tropospheric debris from a Pacific test would be sufficiently concentrated to produce a rainout with such dramatic effects as those noted in 1953 in the Troy, N.Y., area where there was suddenly observed a rapid rise in gross background radioactivity. In general, we are concerned with areas in which the external radiation dose from fallout may be higher by a factor of two or three than in an adjacent area and the average strontium 90 in the soil be double that in adjacent areas.

We have reviewed the trajectories from the larger (10 kilotons and above) shots from Operation Plumbob (1957). Several of them passed over the Dakota-Minnesota area simultaneously with observed rainstorms in that area. Thus, there is every reason to believe that heavy direct contamination of forage contributed to the abrupt rise in strontium 90 content of milk in the Mandan, N. Dak., area in August 1957. The fact that the levels gradually fell off, and throughout calendar year 1958 did not exceed 23 strontium units, is presumptive evidence that the higher figures the previous year resulted from some mechanism involving the bypass of the soil. It is interesting to note that as of August 1958 the soil strontium 90 was 45 mc. Sr<sup>90</sup>/sq.m., a value which might be called average for the United States in 1958. Equally striking was the fact that of seven samples of 1956 Minnesota wheat, each from a different part of the State, no sample contained more than 77  $\mu$ g Sr<sup>90</sup> per kilogram of wheat, while the mean value was 45; in 1957 of seven samples of Minnesota wheat (from essentially the same areas), no sample contained less than 47  $\mu$ g Sr<sup>90</sup> per kilogram, while the mean value was 67; yet in 1958 of nine such samples the highest value was 60 and the mean was again 45. Whole cereal grains are particularly likely to show a high strontium 90 content in years in which an especially heavily contaminated rain occurred while the grain was maturing. British scientists have demonstrated experimentally that this is the case. For corn, of course, there would be little chance for surface contamination of the ear to get into the kernel.

Our pasture program has demonstrated that the buildup of strontium 90 in the soils has been steady and the rate of buildup varies from area to area. In any given region it is quite clearly related to annual rainfall. As the seasons pass there are wide fluctuations in the strontium 90 content of the fodder but the uptake of strontium 90 in the animal zones is a relatively steady process. These observations have substantiated the soundness of the philosophy of the ICRP and the NCRR. These bodies hold that it is the strontium 90 content of the total diet, and averaged over periods of time of up to a year, which will determine the rate of accumulation of strontium 90 in bone. The significance of relatively high values in wheat will depend on the values for strontium 90 in the total diet. In this country, of course, the value for strontium 90 in the milk and milk products consumed is especially important. The eventual uptake in bone will almost certainly not exceed in strontium units that of the milk and milk products in the diet. In fact, unless extreme levels in wheat or some other dietary constituent are consumed year in and year out, the bones will have a lower strontium 90 calcium ratio than the milk.

In the final analysis, we are interested in the incidence of possible somatic effects of deposited strontium 90 in the human population. The most pessimistic assumptions usually made about the effects of fallout are related really to statistical probabilities of individuals (in a population) having difficulties.

The view which one adopts depends upon what is assumed about these statistical relationships between the somatic effects of concern—bone cancer and leukemia induction—and the body burden of strontium 90. If a true threshold exists, as was postulated in the testimony of Dr. Brues and Dr. Law, the effect of body burdens below the threshold value is essentially zero. If, on the other hand, cancer and leukemia induction are in direct proportion to radiation dose irrespective of dose rate—the so-called linear hypothesis—then, insofar as total



effect is concerned, " \* \* \* it is the average dose over the entire population of the U.S. which is important, and local hot spots do not have the alarming significance that is often attributed to them" (Lewis' testimony). Thus, whereas on the linear hypothesis individuals with two, three, or four times the average body burden would have no more than two, three, or four times greater chance of developing bone cancer or leukemia, these individuals would, on the hypothesis of dose-rate dependency, have chances greater than twofold, threefold, or fourfold. However, for the strontium 90 levels in bone with which we are concerned here (or for the levels predicted by the fallout prediction panels): it is virtually certain that the chances for bone cancer or leukemia induction predicted on a dose-rate dependency hypothesis would be extremely low even for higher body burden individuals and would be less than the probabilities predicted on the linearity hypothesis.

CONGRESS OF THE UNITED STATES,  
JOINT COMMITTEE ON ATOMIC ENERGY,  
June 17, 1959.

Gen. A. R. LUEDECKE,  
General Manager, U.S. Atomic Energy Commission,  
Washington, D.C.

DEAR GENERAL LUEDECKE: After reviewing the Commission's supplementary statement on the hotspot problem, which was requested by the Subcommittee on Radiation, in connection with the recent hearings on fallout from nuclear weapons tests, I believe some clarification is still required on the specifics of the question for purposes of a meaningful record.

In particular, it is requested that the Commission provide the subcommittee with specific information on the actual levels of strontium 90 as measured in the various hotspot areas such as Minnesota and North Dakota, together with an interpretation of this information. If such data are not available, the subcommittee would like to know what measures would be required to obtain such data and what increase in the current level of support would be needed.

The subcommittee would also like the Commission's comments on how these specific levels of strontium 90 activity in the hotspot areas, referred to above, relate to present standards on maximum permissible concentrations for the population as a whole.

The Commission's cooperation in providing this further material to the subcommittee is appreciated.

Sincerely yours,

CHET HOLIFIELD,  
Chairman, Subcommittee on Radiation.

ATOMIC ENERGY COMMISSION,  
Washington, D.C., July 24, 1959.

Hon. CHET HOLIFIELD,  
Chairman, Subcommittee on Radiation,  
Joint Committee on Atomic Energy,  
Congress of the United States.

DEAR MR. HOLIFIELD: This is in reply to your letter of June 17, 1959, in which you request further information concerning strontium 90 levels in hotspot areas.

Supplementary information is provided in the attached statement and appendixes which give specific information on measured levels of strontium 90 in hotspot areas, together with interpretation of the data and comparison with currently recommended levels. The data given here permit a reasonably good assessment of the range of concentrations of strontium 90 in various areas and in various items of food.

As you will see, these data indicate that (1) strontium 90 soil values in the areas of interest (because of relatively high levels of fallout occurring during the course of certain weapons tests) are not higher than the average for the United States as a whole; (2) these particular areas, considered from the standpoint of strontium 90 contamination over the long term, which is the important consideration now, should not be considered as hotspots.

In the attached supplementary statement, levels of activity are compared with maximum permissible levels recommended by the ICRP. In summary,

estimates of total dietary strontium 90, referred to as a "maximum diet" applicable to the population of the North Central States is calculated to be 16 microcuries of strontium 90 per kilogram of food. This is to be compared with the ICRP recommended level of 100 as the maximum permissible level for populations outside controlled areas, and 33 as their "suggestion" for the average concentration in the diet of the whole population.

Our budget for the fiscal year 1960, now before the Congress provides for some expansion of our monitoring, sampling, and analysis program. This expansion will permit more detailed identification of areas of variations and better estimates of such factors as variation in average dietary content and in human uptake.

A massive sampling program designed to give detailed coverage of every case of higher-than-average level of radioactivity is beyond our present fiscal and physical capability. It is felt that there are practical limits to the detail of monitoring which can be justified for purposes of surveillance and evaluation. More detailed sampling would be appropriate if present studies indicated a reasonable probability of levels of radioactivity requiring some specific action in the interest of the public health.

I am pleased to submit this supplementary material, and will provide additional information if it should be desired.

Sincerely yours,

A. R. LUEDECKE, General Manager.

#### Enclosure:

Report: "Supplementary Information on the Hotspot Problem" (see below).

Appendix A. "Strontium 90 Data for Certain Areas" (p. 2121).

Appendix B. "North Dakota Strontium 90 Analyses" (p. 2128).

Appendix C. "Tabulation of Findings, Public Health Service Radiation Surveillance Network" (filed with Joint Committee).

Appendix D. "Fallout From Nuclear Tests at the Nevada Test Site" (see p. 2021).

Appendix E. "Dietary Strontium 90 Estimates for the United States," dated May 11, 1959 (p. 2130).

#### SUPPLEMENTARY INFORMATION ON THE HOT SPOT PROBLEM

##### INTRODUCTION

On June 2, 1959, the Commission submitted a statement entitled "The Hot Spot Problem and Worldwide Fallout" in response to a request from Chairman Chet Holifield of the Subcommittee on Radiation, JCAE, as an outgrowth of the public hearings on fallout from nuclear weapons tests, which had been held in May 1959.

In a second letter dated June 17, 1959, Chairman Holifield asked that the Commission provide the subcommittee with specific information on the actual levels of strontium 90 as measured in the various hot-spot areas such as Minnesota and North Dakota, together with an interpretation of this information. The present statement is intended to provide the information and interpretation requested. The material which follows consists of a summary discussion of the actual measured levels of strontium 90, and interpretation of the data in terms of maximum permissible levels, and five appendixes containing the detailed data, as follows:

Appendix A. "Strontium 90 Data for Certain Areas."

Appendix B. "North Dakota Strontium 90 Analyses."

Appendix C. "Tabulations of Findings, Public Health Service Radiation Surveillance Network," for the period May 17, 1957, through March 31, 1959 (19 memorandum reports dated August 23, 1957, to June 15, 1959).

Appendix D. "Fallout from Nuclear Tests at the Nevada Test Site," by Gordon M. Dunning (identical to the statement previously submitted to the public hearings on fallout from nuclear weapons tests, May 5-8, 1959).

Appendix E. "Dietary Strontium 90 Estimates for the United States," by John H. Harley (memorandum to files dated May 11, 1959).

<sup>1</sup> On file with the joint committee.

<sup>2</sup> See p. 2021.

## SUMMARY DISCUSSION OF MEASURED LEVELS

Appendix A contains the specific strontium 90 data which were available at the time of the fallout hearings in May 1959. These data formed the basis for the previous statement entitled "The Hot Spot Problem and Worldwide Fallout." The North Dakota data in appendix B have been obtained since that statement was prepared. These new data tend to confirm the general levels indicated by the earlier North Dakota data. However, they also serve to establish somewhat more completely the variability within the North Dakota area.

For example, new milk data obtained by the Lamont Geological Observatory are given in appendix B representing May 1958 samples from five of the seven major sectors which supply milk to the Mandan, N. Dak., powdered milk plant. The levels range from 8.7 to 35.8 strontium units (micromicrocuries strontium 90 per gram calcium) with an average of 19.1. For comparison, the previously available monthly pooled samples from Mandan, analyzed by the AEC Health and Safety Laboratory (data given in appendix A) showed 21.3 strontium units for May 1958. These data suggest that the pooled sample is reasonably representative of the average contamination level over a broad area such as the State of North Dakota and that in smaller subdivisions of this broad area variations from half to double the average can be expected. Assuming that the local variability was as great in the summer of 1957, when the measured strontium 90 level in the Mandan pooled milk sample reached its maximum of 32.7 strontium units, local levels within the Mandan milkshed could possibly have reached a temporary maximum of 60 units or more. On the other hand, new data on monthly milk samples from Bismarck, N. Dak. (app. B) show a maximum of only 18.0 strontium units occurring in September 1957, and are consistently much lower than the Mandan samples for corresponding months.

New data are also given in appendix B on seven soil samples collected in the Mandan area in August 1958. They show strontium 90 levels ranging from 22.9 to 47.4 millicuries per square mile in the top 2 inches with an average of 35.2 which are consistent with the previously available HASL measurements of 40.2 and 44.8 millicuries strontium 90 per square mile in samples of the top 6 inches collected at Mandan in June 1958 by the U.S. Department of Agriculture. The soil strontium 90 levels at Williston and Bismarck (app. B) are somewhat lower than that at Mandan. All the North Dakota soil data now available indicate a range from 13.5 to 47.4 millicuries per square mile in the top 2 inches of soil as of mid-1958, a variation of some 60 percent above and below an average level of about 30.

For comparison, the average of U.S. soils in the latitude band 40° to 50° north (which includes North Dakota) was 47 millicuries per square mile for the top 6 inches. This is higher than the Mandan soil level for this same depth of sampling. The Mandan area, in turn, appeared to be higher than the average for the State as a whole. Thus, it seems that the North Dakota area cannot be considered a "hot spot" in terms of accumulated strontium 90 contamination of the soil.

A comparison can also be made between the new data on strontium 90 in 1958 wheat from North Dakota and similar data previously available from Minnesota. Six North Dakota wheat samples given in appendix B fall in the range 29 to 54 micromicrocuries strontium 90 per kilogram of wheat with an average of 43.5. For comparison, the 9 samples of 1958 Minnesota data previously available (app. D, table VII), range from 35 to 60 micromicrocuries strontium 90 per kilogram, with an average of 44.4, showing very close similarity both in the mean and in the variability.

Data from California and Utah are included in appendix A because unusual environment radioactivity levels have, at times, created public concern in those States. It should be pointed out, and will be clear from an inspection of the data, that strontium 90 levels are not abnormally high in these areas. The California fallout incidents have involved transient high levels of air activity, and the Utah incidents have involved primarily external gamma radiation from fresh fallout. These incidents are covered fully in appendix D.

Appendix C, while not containing strontium 90 data explicitly, does serve to document the major fallout occurrences associated with Operation Plumbob and to indicate their extent and relative severity. For example, during 1957, rain measurements indicating a deposition of total fission product radioactivity exceeding 386,000 micromicrocuries per square meter (1 curie per square mile) in a 1- or 2-day period were recorded on the following occasions:

## 1957 rains with total radioactivity exceeding 1 curie per square mile

| Station             | Date           | Beta radioactivity in precipitation |            | Approximate age (days) |
|---------------------|----------------|-------------------------------------|------------|------------------------|
|                     |                | $\mu\text{C}/\text{m}^2$            | Me/sq. mi. |                        |
| Atlanta, Ga.        | June 28-29     | 571,000                             | 1,480      | 1-6                    |
| Cheyenne, Wyo.      | Aug. 27-29     | 471,000                             | 1,220      | 6-12                   |
| Denver, Colo.       | Aug. 22        | 759,000                             | 1,970      | 4                      |
| Indianapolis, Ind.  | June 28-29     | 977,000                             | 2,520      | 7                      |
| Iowa City, Iowa     | July 13-14     | 601,000                             | 1,570      | 7-12                   |
| Do.                 | Aug. 26-27     | 2,244,000                           | 5,800      | 3-7                    |
| Do.                 | Oct. 15-16     | 536,000                             | 1,340      | 7-12                   |
| Jefferson City, Mo. | July 9-10      | 2,637,000                           | 7,600      | 7                      |
| Do.                 | Aug. 21        | 824,000                             | 2,130      | 3                      |
| Do.                 | Sept. 7        | 905,000                             | 2,390      | 1                      |
| Do.                 | Oct. 15-16     | 483,000                             | 1,250      | 11-16                  |
| New Orleans, La.    | July 31-Aug. 1 | 438,000                             | 1,140      | 9-11                   |
| Do.                 | Aug. 30-31     | 577,000                             | 1,490      | 1-3                    |
| Pierre, S. Dak.     | Sept. 5        | 568,000                             | 1,470      | 4                      |
| Do.                 | Sept. 18       | 1,338,000                           | 3,460      | 3                      |
| Richmond, Va.       | July 23-24     | 425,000                             | 1,100      | 7-15                   |
| Do.                 | Sept. 9-10     | 834,000                             | 2,220      | 3-5                    |

In each case the age of the debris, estimated from the rate of radioactive decay, as well as the association with cloud trajectories estimated from upper air wind data, indicate an origin in one or more of the detonations in the Plumbob series. The Plumbob cloud trajectories are illustrated in appendix D.

The strontium 90 content of fission debris is less than 1/20,000 of the total radioactivity in the first 2 days after detonation and increases gradually to 1/10,000 in 4 days, 1/5,000 in 8 days, and 1/2,000 in 25 days. From this it can be estimated that the total strontium 90 contribution of these rains would have been in the neighborhood of 2 millicuries per square mile at Iowa City, Iowa, and Jefferson City, Mo. Actual monthly measurements of strontium 90 fallout at Vermillion, S. Dak., for June, July, and August 1957 indicate a total of 4.9 millicuries per square mile (app. A).

The Plumbob series could thus have contributed some 10 to 20 percent to the accumulated soil strontium 90 levels in the summer of 1957. The Plumbob contribution to the strontium 90 content of the crops growing at the time of these particular rains, however, must have been considerably greater. Each crop is found to take up at most only a few percent of the strontium 90 contained in the soil. The fraction absorbed directly from rain can be several times as great under suitable circumstances.

This evidence from shot dates, wind trajectories, and measured daily fallout levels at stations in the North Central States, when taken together with the observed decrease of wheat and milk contamination from 1957 to 1958, leads us to feel that direct absorption of strontium 90 from Operation Plumbob contributed an important part of the hot-spot levels observed in 1957. However, it should be pointed out that fallout rates in individual rains and in monthly pot collections have generally been higher in the Northern than in the Southern States, regardless of the source of the fallout. For example, individual rains of nearly comparable radioactivity have occurred occasionally at some of these same stations during 1958 when no Nevada tests were in progress. Thus the possibility cannot be ruled out that dietary contamination levels in the North Central States would have been higher than the U.S. average even in the absence of direct uptake from fresh Nevada debris.

Estimates of total dietary strontium 90 for both average and high mean contamination levels during 1958 are given in appendix E, based on available measurements in the five major food categories. These indicate a "maximum diet" of 31 strontium units applicable to the population of the North Central States for that year as compared to a nationwide average of 15 strontium units. These levels can also be expressed as 16 and 8 micromicrocuries of strontium 90 per kilogram of food, respectively.

In summary, these studies show that: (1) strontium 90 soil values in the areas of interest (because of relatively high levels of fallout occurring during the course of certain weapons tests) are not higher than the average for the United States as a whole, (2) these particular areas, considered from the standpoint of strontium 90 contamination over the long term, which is the important consideration now, should not be considered as "hot spots."

## COMPARISON WITH RECOMMENDED MAXIMUM PERMISSIBLE LEVELS

The National Committee on Radiation Protection, in National Bureau of Standards "Handbook 69," recommends as the maximum permissible concentration in water, for occupational exposure, 1,000 micromicrocuries of strontium 90 per liter.

With respect to persons outside the controlled area, they recommend: exhibit No. 1, NBS "Handbook 69," page 6: "The maximum permissible average body burden of radionuclides in persons outside of the controlled area and attributable to the operations within the controlled area shall not exceed one-tenth of that for radiation workers." This will generally entail control of the average concentrations in air or water at the point of intake, or of the rate of intake to the body in foodstuffs, to levels not exceeding one-tenth of the maximum permissible concentrations allowed in air, water, and foodstuffs for continuous occupational exposure. The body burden and concentrations of radionuclides may be averaged over periods up to 1 year."

Their recommendation with respect to foods is as follows:

Exhibit No. 2, NBS "Handbook 69," page 21: "The (MPC) values listed in table 1 may, with caution be applied to foods but to use the (MPO) for the 168-hour week without correction for actual intake amounts to assuming that 2,200 grams\* of the individual's food (i.e., substantially all his food), is contaminated at this level and that this situation will persist for 50 years, or until equilibrium is reached in the body. Obviously, a correction factor to take account of the food intake is needed, but to simply use the ratio of 2,200 grams to the grams of intake of a particular food (e.g., butter) as correction factor amounts to assuming no other foods or beverages are contaminated. Again all the factors in the total situation must be considered and great judgment must be used in making such corrections."

To comply with these three recommendations the average concentration of strontium 90 in the diet should not exceed 100 micromicrocuries per kilogram.

Except for exposure to the reproductive cells, the National Committee on Radiation Protection makes no further recommendations applicable to the general public. The International Commission on Radiological Protection, after making equivalent recommendations, goes somewhat further with the following statements.

Exhibit No. 3, recommendations of the International Commission on Radiological Protection (adopted Sept. 9, 1958), page 16: "(06) No specific recommendations are made at this time as to the maximum permissible 'somatically' relevant dose to the population. However, it is expected that the maximum permissible limits of the individual total doses recommended in paragraphs 46-57 will keep the average dose in any time at such a level that the injuries that could possibly occur in a population would be well within acceptable limits."

Exhibit No. 4, *ibid.* page 13: "(56) The individual maximum permissible annual dose will not be exceeded from internal exposure of any single organ. If the release of radioactive material is planned on the basis of one-tenth of the maximum permissible concentration (i.e. 200 strontium units) (MPC) in air or water as given for continuous occupational exposure ('168-hour week') given in the report of committee II."

Exhibit No. 5, *ibid.* page 18: "(08) There remain for further consideration those isotopes that concentrate in specific organs (other than the gonads). In view of the existing uncertainty as to the dose-effect relationships for somatic effects, it is suggested [italic supplied] that for planning purposes the average concentrations of such isotopes, or mixtures thereof, in air or water applicable to the population at large, should not exceed one-thirtieth of the MPC values for continuous occupational exposure given in the report of committee II."

Both the NCRP and the ICRP recommend that in cases in which the body tissue under consideration received radiation from more than one radioisotope, contributions from additional radioisotopes should be taken into account. For reasons of relatively small uptake or relatively short half life, the dose to the bone from other radioisotopes in fallout is smaller than that due to strontium 90 unless most of the exposure is to recently produced material.

\* Based on continuous occupational exposure for a 168-hour week.  
\* The average daily intake of water for the standard man.

As applied to strontium 90 in the diet, these recommendations may be summarized as follows:

(1) The strontium 90 content of the diet of any individual, averaged over the entire diet for periods up to 1 year, should not exceed 100 micromicrocuries per kilogram.

(2) The ICRP suggests that the average concentration of strontium 90 in the diet of the whole population should not exceed 33 micromicrocuries per kilogram.

Only the first of these recommendations is relevant to the question of the significance of variations of concentrations of radioactivity from one area to another.

In comparing observed levels of concentrations of strontium 90 in the diet with recommended maximum permissible limits, it should be borne in mind that the purpose of such limits is to prevent the accumulation of excessive quantities of radioactivity in the body—in this case, in the skeleton. To the extent that it is practical, the best indication of the significance of dietary levels is the concentration of strontium 90 actually found in the bones of those persons most nearly in equilibrium with their environment—young children. At the present time observed concentrations in North America average about 1 percent of the 200 strontium units, the currently recommended concentration for individuals outside of a controlled area, with some concentrations several times this average.

It should further be borne in mind that recommended maximum permissible levels are not levels which mark a boundary between safety and danger. This point was covered more fully in the discussion of maximum permissible levels by Dr. Charles L. Dunham in his opening testimony at the fallout hearing in May 1959.

## APPENDIX A

## STRONTIUM 90 DATA FOR CERTAIN AREAS

The strontium 90 data for certain areas of interest in the following tables have been extracted from various reports. The areas considered are (1) Nevada test site and adjacent areas (Nevada-Utah), (2) California, and (3) Minnesota-North Dakota-South Dakota. These areas are considered because of relatively high levels of fallout occurring during the course of weapons testing although, as may be seen from the tables, strontium 90 levels may not be higher than the average for the United States and would not be considered as hot spots from that standpoint.

A great deal of data tabulated below has been obtained from Health and Safety Laboratory reports, HASL-42 and HASL-65. The statement submitted for the hearings by Dr. Lyle T. Alexander of the U.S. Department of Agriculture was the source for some of the soil data. The statement of C. P. Straub of the U.S. Public Health Service was used for some of the milk data.

1. *Water samples.*—Tracerlab, Inc., collects and analyzes tapwater samples on a monthly basis at Richmond, Calif. These provide an indication of the strontium 90 intake from water in this area. These data are shown on page A-3. Strontium 90 levels in reservoirs following higher than usual fallout in California in the spring of 1958 are also shown.

2. *Milk samples.*—The strontium 90 content of monthly milk samples collected and analyzed by the Public Health Service at Fargo-Moorhead, Sacramento, and Salt Lake City are shown on pages A4-8. Data for powdered buttermilk samples from Mandan collected by the Health and Safety Laboratory are shown on pages A-9 and A-10. Human milk samples and some corresponding cow's milk samples were collected by the Health and Safety Laboratory. Strontium 90 analyses for these samples collected during 1957 at Los Angeles and San Francisco are shown on page A-11. Milk levels provide an index of dietary intake of strontium 90.

The California milk samples are relatively low in strontium 90 content even though higher than usual fallout occurred in California during some Nevada and U.S.S.R. tests. The strontium 90 levels in Mandan milk increased abruptly in 1957 and gradually fell off to levels found throughout 1958 which provides some indication that the rate of fallout is an important consideration. It appears that direct contamination of forage contributes to the level of strontium 90 in milk and may cause abrupt increases in these levels.

3. *Soil samples.*—The strontium 90 levels as determined by analyses of soil samples at Los Angeles, Rapid City, Salt Lake City, and Mandan are shown on

page A-13. Soil samples obtained as part of the HASL pasture program provide additional data for areas in Utah, California, and North Dakota, which are shown on page A-12. These data provide estimates of the total strontium 90 deposition in these areas at the time of collection.

4. *Monthly fallout collections.*—Samples of fallout and rainfall are collected and analyzed for strontium 90 from Salt Lake City, Vermillion, and Richmond, Calif. These data are shown on pages A14-A17 and provide an estimate of the rate of strontium 90 deposition at these locations.

5. *Gunmed-film measurements.*—Fallout samples collected on gunmed-film are used to estimate strontium 90 levels and deposition rates. Data for certain areas of interest are shown on page A-18. These data supplement other fallout information shown above.

6. *Food samples.*—Analyses of strontium 90 in food samples collected by the Lamont Geological Observatory for Minnesota and California are shown on page A-19. The data for samples of hay collected through the HASL pasture program are shown on page A-21. Samples of Minnesota wheat were sent to HASL by Dr. Maurice B. Visscher of the University of Minnesota Medical School for strontium 90 analyses. These data are shown on page A-22. The levels of strontium 90 in foods and forage may be related to the soil data for these areas. The Minnesota wheat data provide further evidence of the importance of direct contamination by fallout as a cause of abrupt increases of strontium 90 in foods and milk.

7. *Animal bone.*—Animal bone samples were collected and analyzed through the HASL pasture program from areas in Utah, North Dakota, and California. These data are shown on page A-23. These show bone levels of strontium 90 which may be related to other fallout data. Although it is expected that animal bones will have higher strontium 90 levels than human bone, the animal data provide a rough estimate of expected human levels.

TABLE 1.—Tap water samples, Richmond, Calif.

| Period:            | Sr <sup>90</sup> $\mu$ c/liter |
|--------------------|--------------------------------|
| April, 1958.....   | 0.05 $\pm$ 0.01                |
| May.....           | 0.014 $\pm$ 0.002              |
| June.....          | 0.12 $\pm$ 0.01                |
| July.....          | 0.15 $\pm$ 0.01                |
| August.....        | 0.19 $\pm$ 0.03                |
| September.....     | 0.030 $\pm$ 0.001              |
| October.....       | 0.21 $\pm$ 0.04                |
| November 3-28..... | 0.22 $\pm$ 0.01                |
| December 1958..... | 0.22 $\pm$ 0.01                |
| January 1959.....  | 0.22 $\pm$ 0.01                |

TABLE 2.—Reservoir water samples, California

| Location                    | Date         | $\mu$ c Sr <sup>90</sup> /liter |
|-----------------------------|--------------|---------------------------------|
| San Andres No. 1.....       | May 23, 1958 | 0.32 $\pm$ 0.01                 |
| San Fernando Reservoir..... | May 21, 1958 | 0.18 $\pm$ 0.01                 |
| Stone Canyon Reservoir..... | do           | 0.22 $\pm$ 0.01                 |
| Summit Reservoir.....       | May 23, 1958 | 0.34 $\pm$ 0.01                 |
| Claremont Reservoir.....    | do           | 0.36 $\pm$ 0.02                 |

TABLE 3.—USPHS milk samples, Fargo, N. Dak.—Moorhead, Minn.

| Date               | Ca content<br>g/liter | Sr <sup>90</sup><br>$\mu$ c/liter | Date                         | Ca content<br>g/liter | Sr <sup>90</sup><br>$\mu$ c/liter |
|--------------------|-----------------------|-----------------------------------|------------------------------|-----------------------|-----------------------------------|
| June 7, 1958.....  | 1.112                 | 15.6                              | Dec. 4, 1958.....            | 1.165                 | 12.3                              |
| July 6, 1958.....  | 1.108                 | 15.3                              | Dec. 31, 1958.....           | 1.159                 | 12.3                              |
| Aug. 3, 1958.....  | 1.116                 | 10.2                              | Feb. 4, 1959.....            | 1.135                 | 11.8                              |
| Sept. 4, 1958..... | 1.125                 | 14.1                              | Mar. 9, 1959.....            | 1.109                 | 12.2                              |
| Oct. 1, 1958.....  | 1.215                 | 15.0                              |                              |                       |                                   |
| Oct. 30, 1958..... | 1.166                 | 11.5                              | Average to Mar. 9, 1959..... |                       | 13.1                              |

TABLE 4.—USPHS milk samples, Sacramento, Calif.

| Date                | Ca Content<br>g/liter | Sr <sup>90</sup> $\mu$ c/liter | Date                | Ca Content<br>g/liter | Sr <sup>90</sup> $\mu$ c/liter |
|---------------------|-----------------------|--------------------------------|---------------------|-----------------------|--------------------------------|
|                     |                       | Sample    Average              |                     |                       | Sample    Average              |
| Apr. 11, 1957.....  | 1.133                 | 6.5                            | Apr. 14, 1958.....  | 1.146                 | 10.5                           |
| May 13, 1957.....   | 1.127                 | 6.0                            | May 15, 1958.....   | 1.141                 | 3.8                            |
| June 19, 1957.....  | 1.092                 | 5.0                            | June 15, 1958.....  | 1.123                 | 7.1                            |
| July 22, 1957.....  | 1.102                 | 0                              | July 13, 1958.....  | 1.036                 | 3.3                            |
| Aug. 18, 1957.....  | 1.114                 | 9                              | Aug. 17, 1958.....  | 1.150                 | 6.8                            |
| Sept. 19, 1957..... | 1.090                 | 2.3                            | Sept. 17, 1958..... | 1.161                 | 3.8                            |
| Oct. 14, 1957.....  | 1.141                 | 1.7                            | Oct. 14, 1958.....  | 1.109                 | 1.4                            |
| Nov. 14, 1957.....  | 1.146                 | 0.6                            | Nov. 18, 1958.....  | 1.111                 | 6.1                            |
| Dec. 19, 1957.....  | 1.157                 | 3.2                            | Dec. 14, 1958.....  | 1.166                 | 4.2                            |
| Jan. 15, 1958.....  | 1.167                 | 2.4                            | Jan. 15, 1959.....  | 1.150                 | 4.3                            |
| Feb. 16, 1958.....  | 1.123                 | 2.8                            | Feb. 23, 1959.....  | 1.151                 | 3.9                            |
| Mar. 16, 1958.....  | 1.140                 | 4.2                            | Mar. 16, 1959.....  | 1.133                 | 7.7                            |
|                     |                       |                                |                     |                       | 5.2 (1959)                     |

TABLE 5.—USPHS milk samples

## SALT LAKE CITY, UTAH

| Date                | Ca content<br>g/liter | Sr <sup>90</sup> $\mu$ c/liter | Date                | Ca content<br>g/liter | Sr <sup>90</sup> $\mu$ c/liter |
|---------------------|-----------------------|--------------------------------|---------------------|-----------------------|--------------------------------|
|                     |                       | Sample    Averages             |                     |                       | Sample    Averages             |
| May 16, 1957.....   | 1.114                 | 4.6                            | May 14, 1958.....   | 1.142                 | 3.3                            |
| June 17, 1957.....  | 1.120                 | 6.4                            | June 11, 1958.....  | 1.128                 | 7.1                            |
| July 18, 1957.....  | 1.115                 | 4.9                            | July 15, 1958.....  | 1.068                 | 4.7                            |
| Aug. 11, 1957.....  | 1.125                 | 4.1                            | Aug. 14, 1958.....  | 1.108                 | 4.2                            |
| Sept. 12, 1957..... | 1.126                 | 4.3                            | Sept. 13, 1958..... | 1.207                 | 5.0                            |
| Oct. 16, 1957.....  | 1.167                 | 5.5                            | Oct. 13, 1958.....  | 1.187                 | 3.1                            |
| Nov. 13, 1957.....  | 1.172                 | 4.8                            | Nov. 14, 1958.....  | 1.162                 | 5.2                            |
| Dec. 15, 1957.....  | 1.165                 | 3.0                            | Dec. 16, 1958.....  | 1.161                 | 6.1                            |
| Jan. 15, 1958.....  | 1.164                 | 3.0                            | Jan. 15, 1959.....  | 1.137                 | 4.5                            |
| Feb. 17, 1958.....  | 1.092                 | 2.2                            | Feb. 17, 1959.....  | 1.176                 | 3.4                            |
| Mar. 13, 1958.....  | 1.155                 | 3.0                            | Mar. 16, 1959.....  | 1.149                 | 4.6                            |
| Apr. 14, 1958.....  | 1.131                 | 4.7                            |                     |                       | 4.7 (1959)                     |

## ST. GEORGE, UTAH

|                    |       |     |  |  |  |
|--------------------|-------|-----|--|--|--|
| Mar. 20, 1959..... | 1.161 | 6.0 |  |  |  |
|--------------------|-------|-----|--|--|--|

TABLE 6.—Powdered buttermilk samples, Mandan, N. Dak.

| Period       | $\mu\text{Ci Sr}^{90}/\text{g Ca}$ |
|--------------|------------------------------------|
| 1955—May     | 7.3 $\pm$ 0.3                      |
| June         | 9.2 $\pm$ 0.2                      |
| July         | 6.3 $\pm$ 0.2                      |
| August       | 5.8 $\pm$ 0.3                      |
| September    | 4.7 $\pm$ 0.3                      |
| October      | 6.9 $\pm$ 0.4                      |
| November     | 7.4 $\pm$ 0.3                      |
| December     | 10 $\pm$ 0.5                       |
| 1956—January | 3.5 $\pm$ 0.2                      |
| February     | 8.1 $\pm$ 0.3                      |
| March        | 11 $\pm$ 1.0                       |
| April        | 9.6 $\pm$ 0.8                      |
| May          | 17 $\pm$ 1.0                       |
| June         | 8.7 $\pm$ 0.6                      |
| July         | 6.6 $\pm$ 0.4                      |
| August       | 8.6 $\pm$ 0.8                      |
| September    | 10.7 $\pm$ 0.5                     |
| October      | 8.9 $\pm$ 0.4                      |
| November     | 5.1 $\pm$ 0.6                      |
| December     | 7.4 $\pm$ 0.5                      |
| 1957—January | 4.4 $\pm$ 0.2                      |
| February     | 8.17 $\pm$ 0.13                    |
| March        | 7.38 $\pm$ 0.14                    |
| April        | 6.75 $\pm$ 0.15                    |
| May          | 9.79 $\pm$ 0.14                    |
| June         | 10.91 $\pm$ 0.16                   |
| July         | 17.33 $\pm$ 0.24                   |
| August       | 32.74 $\pm$ 0.36                   |
| September    | 24.24 $\pm$ 0.45                   |
| October      | 25.63 $\pm$ 0.29                   |
| November     | 29.57 $\pm$ 0.26                   |
| December     | 20.11 $\pm$ 0.66                   |
| 1958—January | 15.24 $\pm$ 0.53                   |
| February     | 16.46 $\pm$ 0.63                   |
| March        | 15.57 $\pm$ 0.64                   |
| April        | 21.65 $\pm$ 0.72                   |
| May          | 21.30 $\pm$ 4.34                   |
| June         | 26.28 $\pm$ 0.56                   |
| July         | 26.74 $\pm$ 1.52                   |
| August       | 20.21 $\pm$ 3.00                   |
| September    | 19.44 $\pm$ 1.21                   |
| October      | 20.77 $\pm$ 0.74                   |
| November     | 23.11 $\pm$ 0.78                   |
| December     | 19.25 $\pm$ 0.72                   |
| 1959—January | 20.78 $\pm$ 0.18                   |

TABLE 7.—HASL human milk samples

 $\mu\text{Ci Sr}^{90}/\text{g Ca}$ 

LOS ANGELES, CALIF.

| Date 1957 | Mother's milk | Cow's milk used by mother |
|-----------|---------------|---------------------------|
| July      | 2.00          | 0.75                      |
| Do        | .80           | 2.26                      |
| August    | 4.34          | 1.10                      |
| Do        | $\leq 3.55$   | 1.61                      |
| September | 4.48          |                           |

1 July.

SAN FRANCISCO, CALIF.

|                           | Mother's milk | Cow's milk used by mother |
|---------------------------|---------------|---------------------------|
| Samples collected in 1957 | 0.96          |                           |
|                           | 27.8          | 1.63                      |
|                           | 1.21          | 6.67                      |
|                           | 1.39          | 1.75                      |
|                           | 2.33          |                           |
|                           | 1.94          | .61                       |
|                           | 9.41          |                           |
|                           | 3.46          |                           |
|                           | .13           |                           |
|                           | $\leq 1.94$   |                           |
|                           | 3.04          |                           |
|                           | 2.53          |                           |
|                           | 2.88          |                           |
|                           | 1.06          |                           |
|                           | .77           |                           |

TABLE 8.—HASL pasture program soil samples

| Location        | Site               | Depth (inches) | Date           | mc Sr <sup>90</sup> /sq. ml. |
|-----------------|--------------------|----------------|----------------|------------------------------|
| Logan, Utah     | College Farm       | 0-1            | September 1953 | 0.66                         |
|                 | do.                | 1-6            | do             | 1.48                         |
|                 | Robinson Farm      | 0-2            | Sept. 18, 1954 | 2.60                         |
|                 | do.                | 2-6            | do.            | 1.02                         |
|                 | College Farm       | 0-2            | do.            | 1.29                         |
|                 | do.                | 2-6            | do.            | Lost                         |
|                 | do.                | 0-2            | Oct. 29, 1955  | 9.92                         |
|                 | do.                | 2-6            | do.            | 3.70                         |
|                 | do.                | 0-2            | Nov. 9, 1956   | 5.98                         |
|                 | do.                | 2-6            | do.            | 5.40                         |
| Mandan, N. Dak. | Griffin Farm       | 0-6            | August 1956    | 10.1                         |
| Brawley, Calif. | Irrigation Station | 0-6            | Jan. 5, 1956   | 2.5                          |

TABLE 9.—USDA-HASL soil collections

| Site                            | Depth (inches) | mcSr <sup>90</sup> /sq. ml. |      |      |      |
|---------------------------------|----------------|-----------------------------|------|------|------|
|                                 |                | 1955                        | 1956 | 1957 | 1958 |
| Los Angeles, Calif.             | 0-6            | 2.1                         | 9.9  | 8.3  | 19.0 |
| Rapid City, S. Dak.             | 0-6            | 19.5                        | 30.3 | 31.7 | 73.8 |
| Salt Lake City, Utah            | 0-8            | 13.9                        | 24.1 | 20.6 | 78.0 |
| Average 50°N-40°N United States |                | 11.6                        | 22.0 | 27.0 | 46.9 |

TABLE 10.—USDA soil collections, Mandan, N. Dak., June 1958

| Site | Depth (inches) | mcSr <sup>90</sup> /square miles |
|------|----------------|----------------------------------|
| A    | 0-6            | 44.8                             |
| B    | 0-6            | 40.2                             |

TABLE 11.—Monthly pot fallout collections, Salt Lake City, Utah

| Month                          | Cumulative<br>mc Sr <sup>90</sup> /square miles | Precipitation<br>(inches) |
|--------------------------------|-------------------------------------------------|---------------------------|
| December 1956                  | 0.31 ± 0.02                                     | 1.67                      |
| January 1957                   | 1.11 ± 0.10                                     | 1.37                      |
| February 1957                  | 1.94 ± 0.11                                     | .72                       |
| March 1957                     | 4.33 ± 0.14                                     | 2.18                      |
| April 1957                     | 5.63 ± 0.14                                     | 3.24                      |
| May 1957                       | 7.44 ± 0.14                                     | 3.37                      |
| June 1957                      | 9.05 ± 0.16                                     | 1.47                      |
| July 1957                      | 9.89 ± 0.187                                    | .31                       |
| August 1957                    | 11.268 ± 0.187                                  | 1.69                      |
| September 1957                 | 11.418 ± 0.187                                  | .33                       |
| October 1957                   | 12.008 ± 0.187                                  |                           |
| November 1957                  | 12.417 ± 0.187                                  |                           |
| December 1957                  | 13.050 ± 0.190                                  |                           |
| January 1958                   | 13.76 ± 0.19                                    | .87                       |
| February 1958                  | 14.86 ± 0.20                                    | 2.20                      |
| March 1958                     | 16.33 ± 0.22                                    | 2.19                      |
| April 1958                     | 18.43 ± 0.22                                    | 2.92                      |
| May 1958                       | 18.73 ± 0.23                                    | .30                       |
| June 1958                      | 20.01 ± 0.23                                    | .04                       |
| July 1958                      | 20.97 ± 0.23                                    | .05                       |
| August 1958                    | 20.78 ± 0.26                                    | .25                       |
| September 1958                 | ( <sup>1</sup> )                                | .25                       |
| October 1958                   | 20.88                                           | ( <sup>2</sup> )          |
| November 1958                  | 21.13                                           | 1.13                      |
| Dec. 12, 1958 to Jan. 12, 1959 | 24.20                                           | .54                       |

<sup>1</sup> No data.<sup>2</sup> No data for September 1958 included.<sup>3</sup> Trace.

TABLE 12.—Monthly pot collections, Vermillion, S. Dak.

| Month           | Cumulative<br>mcSr <sup>90</sup> /square mile | Precipitation<br>(inches) |
|-----------------|-----------------------------------------------|---------------------------|
| 1957—April 1957 | 0.51 ± 0.01                                   | 1.35                      |
| May             | 2.25 ± .85                                    | 4.17                      |
| June            | 3.26 ± .07                                    | 2.37                      |
| July            | 6.063 ± 1.54                                  | 4.29                      |
| August          | 7.169 ± 1.55                                  | 1.62                      |
| September       | 8.042 ± 1.73                                  | 3.14                      |
| October         | 8.972 ± 1.83                                  | 1.67                      |
| November        | 9.118 ± 1.83                                  |                           |
| December        | 9.178 ± 1.85                                  |                           |
| 1958—January    | 9.26 ± .19                                    | .22                       |
| February        | 9.64 ± .19                                    | 2.13                      |
| March           | 9.84 ± .19                                    | .52                       |
| April           | 12.38 ± .19                                   | 3.15                      |
| May             | 14.66 ± .21                                   | 1.85                      |
| June            | 14.82 ± .21                                   | 1.09                      |
| July            | 17.24 ± .22                                   | 4.47                      |
| August          | 17.74 ± .22                                   | .19                       |
| September       | 19.03 ± .23                                   | .88                       |
| October         | 18.09 ± .23                                   | 0                         |
| November        | 18.83 ± .23                                   | .94                       |
| December        | 19.04 ± .23                                   | .67                       |

TABLE 13.—Precipitation collections, Richmond, Calif.

| Sampling period |                | Cumulative<br>mcSr <sup>90</sup> /sq. mi. | Precipitation<br>(inches) |
|-----------------|----------------|-------------------------------------------|---------------------------|
| From—           | To—            |                                           |                           |
| Mar. 20, 1958   | Mar. 28, 1958  | 2.824 ± 0.280                             | 4.07                      |
| Mar. 28, 1958   | Apr. 28, 1958  | 5.185 ± .332                              | 5.15                      |
| Apr. 28, 1958   | May 24, 1958   | 5.575 ± .337                              | .80                       |
| May 24, 1958    | June 24, 1958  | 5.748 ± .338                              | .47                       |
| June 24, 1958   | July 25, 1958  | 5.80 ± .34                                | Dry                       |
| July 25, 1958   | Aug. 29, 1958  | 5.97 ± .34                                | Dry                       |
| Aug. 29, 1958   | Sept. 30, 1958 | 6.02 ± .34                                | .05                       |
| Sept. 30, 1958  | Oct. 27, 1958  | 6.05 ± .34                                | .17                       |
| Oct. 27, 1958   | Nov. 24, 1958  | 6.09 ± .34                                | .04                       |
| Nov. 24, 1958   | Dec. 29, 1958  | 6.36 ± .34                                | 1.77                      |
| Dec. 29, 1958   | Jan. 28, 1959  | 7.75 ± .34                                | 4.42                      |
| Jan. 28, 1959   | Feb. 9, 1959   | 7.79 ± .34                                | Trace                     |

TABLE 14.—Gummed film measurements, cumulative Sr<sup>90</sup> deposition (mc/sq. mi.)

| Location              | September<br>1955 | June 1956 | June 1957 |
|-----------------------|-------------------|-----------|-----------|
| Billings, Mont.       | 5.7               | 14.9      | 26        |
| Las Vegas, Nev.       |                   | 17.8      | 23        |
| Los Angeles, Calif.   |                   | 6.8       | 11        |
| Minneapolis, Minn.    | 4.9               | 16.4      | 25        |
| Rapid City, S. Dak.   | 6.1               | 11.6      | 18        |
| Salt Lake City, Utah  | 23.0              | 34.6      | 54        |
| San Francisco, Calif. | 2.1               | 8.9       | 14        |

TABLE 15.—Lamont Geological Observatory food samples

| Location   | Sample           | Date           | Sr <sup>90</sup> μc/g Ca |
|------------|------------------|----------------|--------------------------|
| Minnesota  | Corn             | September 1956 | 1.6                      |
|            | Peas             | June 1956      | 5.8                      |
| California | Asparagus        | April 1957     | 1.8                      |
|            | Lima beans       | May 1957       | 4.6                      |
|            | do               | September 1955 | 10.0                     |
|            | do               | September 1956 | 4.3                      |
|            | Broccoli         | April 1957     | 4.0                      |
|            | Brussels sprouts | October 1956   | 12.0                     |
|            | do               | September 1956 | 4.3                      |
|            | do               | December 1956  | 2.5                      |
|            | do               | November 1956  | 1.1                      |
|            | Cauliflower      | October 1956   | 28.5                     |
|            | do               | April 1957     | 22.5                     |
|            | Spinach          | March 1957     | 13.9                     |
|            | do               | do             | 9.1                      |
|            | do               | do             | 9.5                      |

TABLE 16.—USDA-HASI, vegetable samples, Brawley, Calif.

| Date          | Type                      | Sr <sup>90</sup> μc/g Ca. |
|---------------|---------------------------|---------------------------|
| Jan. 5, 1956  | Lettuce                   | 0.39 ± 0.03               |
| Do            | Broccoli                  | .25 ± .06                 |
| Do            | Peas                      | 1.34 ± .08                |
| Feb. 28, 1957 | Pea pods                  | ≤ 0.3                     |
| Do            | Broccoli                  | 1.10 ± 0.07               |
| Do            | Cantaloupe rind and flesh | ≤ 0.33                    |
| Do            | Cantaloupe seeds          | ≤ 0.24                    |

TABLE 17.—HASL pasture program hay samples

| Location                  | Site          | Date           | Sr <sup>90</sup> $\mu\text{Ci/g Ca}$ |
|---------------------------|---------------|----------------|--------------------------------------|
| Logan, Utah               | Robinson farm | Sept. 18, 1954 | 10 $\pm$ 0.8                         |
|                           | College farm  | do.            | 6.3 $\pm$ .7                         |
|                           | do.           | July 18, 1955  | 19 $\pm$ 1                           |
|                           | do.           | June 10, 1956  | 8.08 $\pm$ .56                       |
| Mandan, N. Dak.           | do.           | June 1958      | 39 $\pm$ 1                           |
|                           | do.           | (Silage)       | 27 $\pm$ 3                           |
|                           | do.           | July 1, 1956   | 21 $\pm$ 2                           |
| Brawley, Calif. (alfalfa) | do.           | Jan. 5, 1956   | 2.13 $\pm$ .22                       |
|                           | do.           | Feb. 28, 1957  | 7.12 $\pm$ .96                       |

TABLE 18.—Minnesota wheat data

[Strontium 90,  $\mu\text{Ci/kg wheat}$ ]

| Location     | 1956 | 1957 | 1958 | Location            | 1956 | 1957 | 1958 |
|--------------|------|------|------|---------------------|------|------|------|
| Rosemont     | 76   | 65   | 36   | Waseca              | 46   | 47   | 40   |
| Southwest    | 71   | 51   | 37   | Northern Minnesota  | 47   | 47   | 42   |
| Grand Rapids | 36   | 81   | 60   | International Falls |      |      | 54   |
| Morris       | 28   | 80   |      | Unknown             |      |      | 54   |
| Duluth       | 38   |      | 35   |                     |      |      |      |
| Crookston    | 17   | 112  | 42   |                     |      |      |      |
|              |      |      |      | Average             | 44.6 | 66.1 | 43.4 |

TABLE 19.—HASL pasture program—Animal bone

| Location        | Site          | Date           | Sr <sup>90</sup> $\mu\text{Ci/g Ca}$ |
|-----------------|---------------|----------------|--------------------------------------|
| Logan, Utah     | Robinson Farm | Fall 1953      | 1.2                                  |
|                 | College Farm  | do.            | 0.6                                  |
|                 | Robinson Farm | September 1954 | 4.4 $\pm$ 0.2                        |
|                 | College Farm  | do.            | 1.7 $\pm$ 0.2                        |
|                 | do.           | October 1955   | 8.2 $\pm$ 0.4                        |
|                 | do.           | May 1956       | 8.4 $\pm$ 0.4                        |
| Mandan, N. Dak. | do.           | Nov. 13, 1956  | 5.3 $\pm$ 0.3                        |
|                 | do.           | Mar. 27, 1956  | 24 $\pm$ 0.6                         |
|                 | do.           | May 1957       | 26.8 $\pm$ 0.5                       |
| Brawley, Calif. | do.           | Feb. 28, 1957  | .67 $\pm$ 0.05                       |

## APPENDIX B

TABLE 1.—North Dakota strontium 90 analyses—Lainont Geological Observatory analyses

## BONE SAMPLES

| LGO No. | Sex    | Age       | Date of death | $\mu\text{Ci Sr}^{90}/\text{g Ca}$ |
|---------|--------|-----------|---------------|------------------------------------|
| 7470    | Female | Fetus     | Mid-1958      | 0.53 $\pm$ .06                     |
| 7471    | Male   | 61        | do.           | .51 $\pm$ .04                      |
| 7472    | do.    | 61        | do.           | <0.04                              |
| 7473    | do.    | Fetus     | do.           | 1.05 $\pm$ .06                     |
| 7474    | do.    | 65        | do.           | .43 $\pm$ .10                      |
| 7475    | do.    | 23        | do.           | .66 $\pm$ .11                      |
| 7476    | do.    | 25        | do.           | 1.19 $\pm$ .14                     |
| 7477    | do.    | 64        | do.           | .53 $\pm$ .08                      |
| 7478    | do.    | 3         | do.           | 2.62 $\pm$ .05                     |
| 7481    | do.    | Stillborn | do.           | 1.34 $\pm$ .26                     |

## MILK

| Location          | LGO No. | Date collected | $\mu\text{Ci Sr}^{90}/\text{g Ca}$ |
|-------------------|---------|----------------|------------------------------------|
| South Soo         |         | May 1958       | 21.27 $\pm$ 0.45                   |
| West of South Soo |         | do.            | 11.16 $\pm$ .48                    |
| McLaughlin        |         | do.            | 8.70 $\pm$ .45                     |
| North Soo         |         | do.            | 35.81 $\pm$ .75                    |
| South Branch      |         | do.            | 18.52 $\pm$ .60                    |
| Bismarck          | 324     | March 1957     | 6.23 $\pm$ .10                     |
| Do                | 325     | April 1957     | 7.98 $\pm$ .12                     |
| Do                | 326     | May 1957       | 11.58 $\pm$ .13                    |
| Do                | 327     | June 1957      | 6.83 $\pm$ .11                     |
| Do                | 328     | July 1957      | 7.34 $\pm$ .10                     |
| Do                | 329     | August 1957    | 12.20 $\pm$ .13                    |
| Do                | 330     | September 1957 | 18.00 $\pm$ .15                    |
| Do                | 331     | October 1957   | 16.12 $\pm$ .17                    |
| Do                | 332     | November 1957  | 15.02 $\pm$ .13                    |
| Do                | 332     | December 1957  | 11.85 $\pm$ .12                    |
| Do                | 617     | January 1958   | 17.6 $\pm$ .9                      |
| Do                | 618     | February 1958  | 13.7 $\pm$ .6                      |
| Do                | 619     | March 1958     | 14.6 $\pm$ .7                      |
| Do                | 620     | April 1958     | 13.6 $\pm$ .7                      |

## SOILS

| Location                                                | Date          | Depth         | Mc Sr <sup>90</sup> /ml <sup>2</sup> |
|---------------------------------------------------------|---------------|---------------|--------------------------------------|
| Williston                                               | August 1957   | 0 to 2 inches | 13.5 $\pm$ 0.6                       |
|                                                         | do.           | 2 to 6 inches | 1.4 $\pm$ 0.5                        |
|                                                         | Aug. 11, 1957 | 0 to 2 inches | 39.8 $\pm$ 0.5                       |
| Mandan, west edge of                                    | do.           | 2 to 6 inches | 1.8 $\pm$ 0.9                        |
|                                                         | August 1958   | 0 to 2 inches | 22.9 $\pm$ 0.3                       |
|                                                         | do.           | do.           | 34.1 $\pm$ 0.4                       |
| Mandan, west of                                         | do.           | do.           | 41.7 $\pm$ 0.6                       |
|                                                         | do.           | do.           | 39.1 $\pm$ 0.4                       |
|                                                         | do.           | do.           | 47.4 $\pm$ 0.5                       |
| Arnold                                                  | do.           | do.           | 22.4 $\pm$ 0.7                       |
| Mandan (10 miles south of, level ground)                | do.           | do.           | 38.1 $\pm$ 0.5                       |
| Mandan (10 miles south of, depression 4 feet 15 inches) | do.           | do.           | 26.8 $\pm$ 0.3                       |
| Bismarck                                                | do.           | do.           | 25.2 $\pm$ 0.4                       |
| Do                                                      | do.           | do.           |                                      |

TABLE 2.—AEC health and safety laboratory analyses—August 1958 wheat crop

FARGO, N. DAK. (NORTH DAKOTA AGRICULTURAL COLLEGE, G. SMITH)

| HASL No. | Type  | $\mu\text{Ci Sr}^{90}/\text{kg sample}$ |
|----------|-------|-----------------------------------------|
| 9587     | Wheat | 54                                      |
| 9588     | do.   | 49                                      |

MANDAN, N. DAK. (AGRICULTURAL EXPERIMENT STATION, E. GEORGE)

| HASL No. | Type             | $\mu\text{Ci Sr}^{90}/\text{kg sample}$ |
|----------|------------------|-----------------------------------------|
| 9599     | Wheat            | 52                                      |
| 9601     | do.              | 34                                      |
| 9600     | do.              | 20                                      |
| 9732     | do.              | 43                                      |
| 9633     | Flour, 1st clear | 16                                      |
| 9634     | Flour, 2d clear  | 31                                      |
| 9635     | Flour, patent    | 18                                      |
| 9731     | Feed middlings   | 161                                     |
| 9636     | bran             | 186                                     |
| 9637     |                  |                                         |
| 9638     |                  |                                         |
| 9730     |                  |                                         |

1 Blind duplicate.

2 Hard, Red Spring, 1958 crop.





TABLE 4.—Diet statistics, cereals and bakery products

| Description            | Weekly intake per household | Annual intake per individual |
|------------------------|-----------------------------|------------------------------|
|                        | Pounds                      | Kilograms                    |
| Cereal products:       |                             |                              |
| Flour.....             | 2.66                        | 19.0                         |
| Mixes.....             | .61                         | 4.3                          |
| Cereals.....           | .82                         | 5.9                          |
| Rice.....              | .30                         | 2.2                          |
| Corn.....              | .92                         | 6.6                          |
| Macaroni.....          | .42                         | 3.0                          |
| Other.....             | .14                         | 1.0                          |
| Bakery products:       |                             |                              |
| White bread.....       | 3.98                        | 28.5                         |
| Whole wheat bread..... | .31                         | 2.2                          |
| Other bread.....       | .42                         | 3.0                          |
| Other products.....    | 1.99                        | 14.3                         |
| Total.....             | 12.56                       | 90.0                         |

TABLE 5.—Strontium 90 levels in milk

| Location            | Mean $\mu\text{C Sr}^{90}/\text{g. Ca}$ |      |
|---------------------|-----------------------------------------|------|
|                     | 1957                                    | 1958 |
| New York City.....  | 4.5                                     | 7.7  |
| USPHS network.....  |                                         | 7.9  |
| United Kingdom..... | 5.4                                     |      |
| Canada.....         | 5.0                                     |      |

TABLE 6.—Strontium 90 levels in cereal products

| Location                                | Mean $\mu\text{C Sr}^{90}/\text{kg.}$ |      |
|-----------------------------------------|---------------------------------------|------|
|                                         | 1957                                  | 1958 |
| Minnesota wheat.....                    | 66.0                                  | 44   |
| Germany: Grains.....                    | 26.0                                  |      |
| United Kingdom:                         |                                       |      |
| National flour <sup>1</sup> .....       | 3.4                                   |      |
| Cereals.....                            | 17.0                                  |      |
| Other data:                             |                                       |      |
| U.S. wheat.....                         | 400 mg. Ca/kg.                        |      |
| U.S. white flour.....                   | 160 mg. Ca/kg.                        |      |
| U.S. weighted mean.....                 | ~200 mg. Ca/kg. cereal products.      |      |
| United Kingdom flour <sup>1</sup> ..... | 1,500 mg. Ca/kg.                      |      |

<sup>1</sup> Fortified with inorganic calcium.

TABLE 7.—Strontium 90 levels in vegetables

| Description           | Mean $\mu\text{C}/\text{kg.}$ |      |
|-----------------------|-------------------------------|------|
|                       | 1957                          | 1958 |
| Kulp: <sup>1</sup>    |                               |      |
| Leafy vegetables..... | 5.7                           |      |
| Potatoes.....         | 4.6                           |      |
| Germany:              |                               |      |
| Vegetables.....       | 12                            | 10   |
| Potatoes.....         | 6                             |      |
| United Kingdom:       |                               |      |
| Vegetables.....       | 6                             |      |
| Potatoes.....         | 7                             |      |

<sup>1</sup> Kulp, J. L., loc. cit.

NOTE.—Other data: Assuming mean ash content to be 1 percent of edible weight to reduce data to common form: Leafy vegetables show 750 mg. Ca/kg.; potatoes show 500 mg. Ca/kg.

TABLE 8.—Estimated dietary strontium 90 contributions, 1958 mean

| Type of food               | Annual quantity | $\mu\text{C Sr}^{90}$ per unit | Total $\mu\text{C Sr}^{90}$ | Grams Ca per unit | Total grams Ca |
|----------------------------|-----------------|--------------------------------|-----------------------------|-------------------|----------------|
| Milk products.....         | quarts          | 233                            | 8                           | 1,860             | 1.0            |
| Cereal products.....       | kilograms       | 90                             | 25                          | 2,250             | .2             |
| Meat, etc.....             | do.             | 98                             | 1                           | 100               | .2             |
| Potatoes.....              | do.             | 45                             | 6                           | 270               | .5             |
| Fruits and vegetables..... | do.             | 193                            | 6                           | 1,160             | .75            |
| Total.....                 |                 |                                |                             | 5,640             | 2.438          |

<sup>1</sup> Estimated as  $\frac{1}{2}$  of 1958 wheat.<sup>2</sup> This value is in disagreement with the 370 reported in table 2. This is probably due to an overestimate here of the calcium content for fruits and vegetables. 370 grams will be used in calculating dietary strontium units.

TABLE 9.—Dietary strontium 90 contributions, hypothetical 1958 hot spot

| Type of food               | Annual quantity | $\mu\text{C Sr}^{90}$ per unit | Total $\mu\text{C Sr}^{90}$ |
|----------------------------|-----------------|--------------------------------|-----------------------------|
| Milk products.....         | quarts          | 233                            | 20                          |
| Cereal products.....       | kilograms       | 90                             | 50                          |
| Meat, etc.....             | do.             | 98                             | 1                           |
| Potatoes.....              | do.             | 45                             | 6                           |
| Fruits and vegetables..... | do.             | 193                            | 10                          |
| Total.....                 |                 |                                | 11,460                      |

<sup>1</sup> Highest mean 1958 level for milk.<sup>2</sup> Based on maximum wheat values.<sup>3</sup> No hot spot data.<sup>4</sup> Based on cumulative  $\text{Sr}^{90}$  deposition.<sup>5</sup> Based on rate of  $\text{Sr}^{90}$  deposition.

NOTE.—This is an extremely unlikely combination of circumstances, where the maximum known sustained values are combined in 1 diet.

TABLE 10.—Mean 1958 dietary strontium 90 contributions, ICRP units

| Type of food                   | Annual quantity   | $\mu\text{C Sr}^{90}$ per unit | Total $\mu\text{C Sr}^{90}$ |
|--------------------------------|-------------------|--------------------------------|-----------------------------|
| Milk products.....             | cubic centimeters | 220,000                        | $0.0085 \times 10^{-4}$     |
| Cereal products.....           | grams             | 90,000                         | $.0250 \times 10^{-4}$      |
| Meat, etc.....                 | do.               | 98,000                         | $.001 \times 10^{-4}$       |
| Potatoes.....                  | do.               | 45,000                         | $.006 \times 10^{-4}$       |
| Fruits and vegetables.....     | do.               | 193,000                        | $.006 \times 10^{-4}$       |
| Other foods <sup>1</sup> ..... | do.               | 65,000                         |                             |
| Total.....                     |                   | 711,000                        | $5.640 \times 10^{-4}$      |

<sup>1</sup> Fats, oils, sugar, etc.<sup>2</sup> Cubic centimeters or grams.UNIVERSITY OF PENNSYLVANIA,  
DEPARTMENT OF PHYSICS,  
Philadelphia, May 12, 1959.HON. CHET HOLIFIELD,  
Joint Committee on Atomic Energy,  
Washington, D.C.

DEAR MR. HOLIFIELD: Although the hearings held by your committee last week originally promised to clarify a number of problems for the Congress and the public, it is unfortunate that some of the most important problems did not receive as clear or definitive a discussion as was hoped. I believe I am not alone, among the members of the panel which sat before the committee to discuss "Status and Implications of Testing," in feeling that several of the most acute problems before the committee were completely passed over in the protracted discussion of matters less directly relevant to the purpose of the hearing; and I should like to submit for the record of the hearings the following remarks on some of these

problems—especially, on hot spots, on the meaningfulness of the MPC, on who should set the "permissible" level for fallout, and on whether there are methods known whereby large nuclear explosions can be carried out without appreciable fallout.

(1) *The problem of "hot spots" in fallout.*—In the report which the above-mentioned panel prepared for the committee, it was explicitly noted that only average levels of fallout were discussed quantitatively, and that these averages made no allowance for local variations in fallout, etc. Now I want to say that I think there are no large groups of people in urgent danger at present. But I wish to make remarks on two points.

(a) People exposed to the higher "hot spot" fallout levels should be given as clear as possible a statement as to just what the extent of the hazard is.

(b) It is the "hot spot" levels rather than broader average levels which should determine the "worry point" for fallout.

I should like to expand on this matter. First, it is worthwhile to note the levels of strontium 90 which are presently encountered by various groups. This is a slightly complicated problem, and so I shall list a few of the steps in the process of estimating these levels.

The best means of estimating the bone levels of strontium 90 which will occur in humans seems at present to be: Calculate the level in the diet, in "strontium units" (1 strontium unit equals 1 micromicrocurie of strontium 90 per gram of calcium), and divide by 4 to obtain the corresponding bone level produced. The average U.S. diet in 1958 contained about 13 strontium units. Correspondingly that diet would produce a bone level of about 3.5 strontium units. (When the present stratospheric store of strontium 90 from past tests has all come down, these diets and bone levels would be increased about twofold. This corresponds roughly to the estimate given in the report of the Fallout Prediction Panel.)

I estimate that for the "hot spot" regions in the north central part of the United States, diet and bone levels three to four times the U.S. average can be expected.

This estimate is arrived at in the following way: From the report prepared by the AEC's Health and Safety Laboratory, giving data on the strontium 90 content of some foods during 1958, one finds that strontium 90 levels in wheat products in the "hot spot" area can be expected to run 100 to 200 micromicrocuries of strontium 90 per kilogram of weight. These levels, as the HASL report notes, were found in bread and wheat purchased in New York City in February 1959. If a person ate nothing but bread as his diet, then since the average diet contains somewhat over 2 kilograms per day the strontium 90 level would be perhaps 200 to 500 micromicrocuries per day. But this does not necessarily mean 200 to 500 strontium units. In order to estimate the strontium unit level it is necessary to know not only the strontium 90 intake but also the calcium intake. Rather than trying to estimate these values for the artificial assumption of a diet of wheat products alone, it is better to consider a more typical diet. The typical U.S. diet apparently includes about one-fourth kilogram of wheat products per day, and about 1.2 grams of calcium per day. From these figures one finds that the total strontium 90 intake at 1958 "hot spot" levels would consist of about 25 to 50 micromicrocuries of strontium 90 from wheat products, plus additional strontium 90 from other sources. If there were no strontium 90 from other sources than the wheat products then the strontium unit level in the diet would be obtained by dividing 25 to 50 micromicrocuries of strontium 90 by 1.2 grams of calcium; this gives 20 to 40 strontium units in the diet. When one adds the additional strontium 90 to be expected from other foods, one obtains an estimated strontium unit level in diet in the northern U.S. "hot spot" area, of 40 to 60 strontium units. The corresponding bone level that would be produced, in this "hot spot" area would be 10 to 15 strontium units.

Thus, for the strontium 90 levels which have been found to exist in foods in 1958, one estimates corresponding bone levels of about 3.5 strontium units average over the United States, and 10 to 15 strontium units in the north central hotspot area.

Even if there are no further tests these levels can be expected to increase. The average level in the United States can be expected to rise to a peak of 6 or 7 strontium units in bone. The bone levels in the north central hotspot area may also rise somewhat, but in this case it is more difficult to estimate how much because we do not as yet have sufficient information on the exact reasons for the high strontium 90 levels in wheat and milk in that area. It is probably reasonable to estimate that the peak bone levels which will occur in appreciable numbers of people who eat food principally coming from "hot" regions

will be 10 to 20 strontium units, if no further atmospheric contamination is produced.

Bone levels of 10 to 20 strontium units, while not, in my opinion, constituting a great hazard, will produce additional radiation in the bones of approximately 25 to 50 percent of the average natural background dose rate. (The radiation level in the bone marrow produced by this strontium 90 level will probably be less—perhaps only 10 to 30 percent of natural background.) It is not sufficient, of course, to describe fallout levels only in terms of the averages, which for human bone in the United States will reach of the order of 10 percent of natural background as a result of past tests. It is in fact true that in hotspot areas in this country, and similarly in hotspot areas elsewhere, fallout from past tests will produce peak radiation doses to the bone which will be a considerably larger fraction of the background dose. It should be noted that in the Far East, where cereals constitute a larger fraction of the diet than is true for the United States, "hotspot" bone levels can be expected which for quite large numbers of people may be comparable to the levels produced from "hot" areas in the United States; that is, past tests may result in peak bone dose rates of the order of 25 to 50 percent above the dose rate from natural background.

It is necessary to repeat at this point that even levels as high as 25 to 50 percent of natural background cannot be regarded as constituting a grave danger. Nevertheless, such levels, it seems to me, are high enough that serious weight should be given to the fallout problem in considering the continuation of nuclear explosions which can add additional contamination to the atmosphere.

(2) *The meaningfulness of the maximum permissible level concept for fallout.*—I believe that one of the very most important results that should come from these fallout hearings is the realization, on the part of both Congress and the public, that no group of scientists can set a "permissible level" for fallout. Groups of scientists, even those especially concerned with radiation hazards, such as the ICRP, cannot properly carry out the task of weighing the damage produced by fallout against the arguments for continuing development of nuclear weapons. The decision as to what fallout level is acceptable must be made (in this country) by Congress itself; and in this decision the Joint Committee on Atomic Energy must take the major responsibility.

I cannot stress this point too strongly. I do not mean to suggest that fallout effects constitute the strongest reason for trying to achieve a nuclear test cessation. But I do not think that Congress can ask scientists to tell it what is an acceptable level of fallout. The responsibility lies with the Members of Congress themselves.

(3) *The question whether there are methods known whereby large nuclear explosions can be carried out without appreciable fallout.*—On this subject I wish to give particular attention to two points.

(a) The misleading implication that explosions above 30 miles would not produce appreciable fallout, carried by the recent proposal of the United States for a "first phase" cessation of atmospheric test.

(b) The possible usefulness of certain proposals advanced by Dr. Libby in his statement at the hearing, on methods of testing without appreciable fallout.

As for the fallout to be expected from explosions above 30 miles: As I suggested at the hearings, and as Dr. Libby agreed, there is no good reason to believe that long-lived fallout will be appreciably less for explosions somewhat above 30 miles than for explosions much closer to the earth's surface. There is in fact reason to believe that even explosions carried out several hundred miles above the earth might deliver 50 to 100 percent of the long-lived fallout down onto the surface of the earth.

This whole matter is of especial importance because the objection of the U.S.S.R. to this 30-mile proposal has been attacked by the U.S. press as indicating dishonesty by Russia regarding fallout danger, whereas in fact the U.S. proposal was phrased in terms which encouraged incorrect and self-deceiving interpretation in the United States.

The evaluation of the dangers of fallout, and proper weighing of fallout effects in making decisions on nuclear weapons testing, is a complex matter at best. It is very unfortunate when official statements connected with fallout are put in a way which is very likely to create misunderstanding.

As for possible methods of testing large weapons without producing appreciable fallout, I should like to comment on some of the possibilities suggested by Dr. Libby. First, it was unfortunate that the question whether large weapons can be exploded underground without danger from the radioactive products was

essentially not discussed at the hearings. When the hearings were being planned, we all hoped that this subject would be explored in the hearings.

As for Dr. Libby's suggestion that it may be possible to contain fallout particles in the case of a large surface explosion by using perhaps several hundred tons of sand as a fallout-particle absorber, this seems to me impractical. The energy from a 10-megaton bomb, for example, is sufficient to vaporize millions of tons of material.

As for testing of nuclear weapons at great distances from the earth, it does indeed appear that this could be done without appreciable fallout. If the need for continuing explosions of large weapons were considered compelling enough, this method could in all probability be used in spite of the practical difficulties.

I hope that in the final deliberations of the committee these matters will receive more attention than was possible at the hearings.

It is of the greatest importance that the available facts on fallout be made publicly and clearly available. Only in this way will the Government be able to make proper decisions as to future policy. The hearings held by your committee have been the only means whereby the facts on fallout can be clearly brought out, and I should like to convey to you the appreciation felt by many scientists for the work of this committee.

Very sincerely yours,

WALTER SELOVE.

UNIVERSITY OF PENNSYLVANIA,  
Philadelphia, October 14, 1959.

Mr. JAMES T. RAMEY,  
Executive Director, Joint Committee on Atomic Energy,  
The Capitol, Washington, D.C.

DEAR MR. RAMEY: I am enclosing a copy of my May 27 letter with certain sections indicated which I should like to submit for inclusion in the record. Also, as we discussed, if you include the May 12, letter please delete items 2 and 3 from it, as I have discussed them elsewhere.

Sincerely,

WALTER SELOVE.

MAY 27, 1959.

Congressman CHET HOLIFIELD,  
House Office Building,  
Washington, D.C.

DEAR MR. HOLIFIELD: Thank you for your letter of May 14. I am sorry not to have been able to answer earlier, due to a most crowded schedule.

I was very interested in your comment that it might be possible to have some additional hearings at a convenient time in the future on the subject of fallout from nuclear tests. I think this would be very worthwhile because the hearings this May were so crowded for time to provide sufficient discussion of a number of important points.

In reply to your letter, I should like to mention a few points which occurred to me as calling for further discussion before your committee.

#### 1. Hot spots in North Central United States, and high strontium 90 levels in grain

A number of points deserve attention here. What is known about the cause of the high strontium levels in Minnesota and North Dakota wheat. Have these been unusually high because of a high rate of fallout? (It is impressive to note that the fallout in a part of North Dakota on a single day in 1957 was 22 mc./mi.<sup>2</sup>—this was about equal to the total accumulation average over the United States at that time.) If the high grain levels have indeed been due mostly to the high rate of fallout, then it can be expected that if tests stop, these levels in grain will drop sharply. On the other hand if the high grain levels are found to be associated with low calcium content in the soil then grain from the "hotspot" areas will continue to show high strontium 90 levels for some time even after no further test explosions occur. It might be useful to request testimony on this subject from Dr. Maurice Vlsscher, as well as others.

#### 2. Permissible dose for large populations

It would be worth while having further discussion of the factors behind the recent action of the National Committee on Radiation Protection, in which the permissible strontium 90 level for occupational exposure was doubled. How

does the new recommendation compare with recommendations of the International Commission on Radiological Protection? (This subject may have been discussed in the hearings but I did not observe it.) The new higher level recommended by NCRP produced the inference by the general public, of course, that strontium 90 is less dangerous to the general public than had been previously thought. It should be made clear that there is virtually no connection between the recommended occupational permissible level and the effects of much lower doses on a large population. Does the NCRP plan to issue any recommendation as to permissible strontium 90 dose for a large population? And, if so, how does that recommendation compare with the one by the ICRP?

What about the problem of nonuniform deposition of strontium 90 in bone? I have seen reports of a Swedish work suggesting that because of great non-uniformity of deposition the "permissible level" for strontium 90 should be very much lower. It would be useful to have expert testimony discussing this point.

#### 4. Summary discussion evaluating the seriousness effects from test fallout

It was my hope and expectation that the panel discussion on the last day of the hearings would give considerable attention to the evaluation of the effects of test fallout. Unfortunately, because of all the time that was occupied with the question of testing bombs in outer space, this problem of evaluation was never taken up. As you know, I feel particularly strongly that no group of scientists can properly be given the responsibility of specifying a "permissible level" for fallout. I also believe that the fallout levels from past tests are sufficiently high—as high as 25 to 50 percent of natural background, over extended areas—that quite serious weight must be given to the fallout problem in making decisions on further explosions of large nuclear devices.

I hope these comments will be of some use. I have the greatest respect for the approach you have taken on the fallout problem, in trying first of all to bring out all the facts. I believe that with a small amount of additional public discussion of fallout problems before your committee a great improvement in public understanding of this complicated subject can result.

Sincerely yours,

W. SELOVE.

UNIVERSITY OF PENNSYLVANIA,  
DEPARTMENT OF PHYSICS,  
Philadelphia, September 21, 1959.

Mr. JAMES T. RAMEY,  
Executive Director, Joint Committee on Atomic Energy,  
The Capitol, Washington, D.C.

DEAR MR. RAMEY: I have looked through the recent material on the hotspot problem that you kindly made available to me. As per our recent telephone conversation, I am sending the enclosed comments for possible inclusion in the record of the hearings on fallout from tests. If this material reaches you in time for inclusion, I should like to request that you also include a copy of my letter which was printed in the Washington Post on September 7, that letter also contains remarks relevant to the hotspot problem.

Sincerely yours,

WALTER SELOVE.

#### FURTHER COMMENTS ESPECIALLY CONCERNING THE HOTSPOT PROBLEM

1. Although a very comprehensive program of fallout measurement and evaluation has been initiated and pursued by the AEC, it is still difficult to separate out very much information on certain detailed aspects of the hotspot problem. For example, one would like to know how extensive an area was affected by the North Dakota fallout of July 18, 1957, reported by Dr. E. W. Pfeiffer in which the Sr<sup>90</sup> fallout density occurring in a single day equaled the total accumulated up to that time over the northern part of the United States.

2. It deserves emphasis that it is not only the total accumulation of fallout in an area which determines the hotspot nature, but also the manner in which the fallout is concentrated in time. This can be seen, for example, from the fact that although the total Sr<sup>90</sup> accumulation to date in the Minnesota-Dakota area is not sharply higher than that at other points of corresponding latitude in the United States, nevertheless relatively large transient increases in Sr<sup>90</sup> levels in milk and wheat from this area were observed, especially in 1957.

When a particularly heavy fallout occurs shortly before harvest of a crop, that crop may correspondingly show unusually high contamination (from fallout material deposited directly on the plant surfaces). An important point here is that this unusually high contamination may then subsequently make its effects felt for a long period, if that crop provides food for many months. It should be noted that a persistence effect of this kind appeared in some U.S. wheat in the period following the 1957 harvest. It should be further noted that this is not the first time such a concentrated effect with a persistence nature has occurred; other examples are reported in the 1958 report of the United Nations Radiation Committee. A particularly prominent example is that of the rice crop in Japan in 1956. There the  $\text{Sr}^{90}$  content of rice averaged 50 to 150 strontium units. This rice, which thus contained more than 10 times the  $\text{Sr}^{90}$  concentration in U.S. food, then constituted a major source of Japanese dietary calcium for many months, for the entire Japanese people.

3. It is important to point out, as is done in the report accompanying General Lueddecke's July 24 letter, that if no further test explosions take place, then areas which have been particularly prominent as hotspot areas will probably not give rise to grave health hazards over the long term. This is so because the total accumulated fallout even in areas such as the Minnesota-Dakota area is not spectacularly higher than in other regions of similar latitude.

At the same time, it should be realized that if further tests giving large amounts of fallout occur, then recurring hotspot effects are to be expected.

4. Evaluation of the seriousness of hotspot effects takes us out of the realm of strictly scientific discussion. With this word of caution, that one cannot claim to evaluate seriousness of fallout effects on purely scientific grounds, I should like to comment further.

Much attention has been drawn to the observation of Dr. E. B. Lewis that "on the linear hypothesis it is the average dose over the entire population . . . which is important and local hotspots do not then have the alarming significance that is often attributed to them . . ." This would be true, on a statistical basis, if the population exposed to hotspot levels were limited to the local population in the hotspot areas. This kind of limited exposure is true for the case of a hotspot effect involving a short-lived isotope, such as the  $\text{I}^{131}$  which Dr. Lewis was primarily discussing. For a long-lived isotope such as  $\text{Sr}^{90}$ , however, the situation can be quite different. As I have tried to point out above, the effects of hotspot fallout can be, and have been, delivered to a much larger population than just the local population of the area.

A particularly heavy fallout affecting an applicable part of a major crop can affect very much larger numbers of people than those living in the relatively small region of the heavy fallout.

5. The impact on people of hotspot levels in food may be expected to be considerably larger than would be true if equivalent total fallout effects were distributed completely uniformly. I should like to discuss this in terms of my own personal reaction to present information on hotspot fallout levels. I am reluctant to bring in such a closely personal evaluation, and I do so only because I do not know of any better way to illustrate a point which calls for understanding.

AEC data reported during the hearings indicated that some wheat and bread purchased off the shelf in New York City contained quite high  $\text{Sr}^{90}$  levels. Clearly, one can expect to encounter these unusually high levels, in some food, anywhere in the country, even though only limited areas received hotspot fallout.

Now whole wheat bread and flour was particularly high. It happens that whole wheat bread is my favorite bread. When I saw the levels that have been found in some samples, I asked myself whether they were high enough to cause me to avoid whole wheat bread.

My answer is the following. Present information indicates that if no further fallout material is released into the atmosphere, then  $\text{Sr}^{90}$  levels in cereal products will drop off from the peak levels so far encountered. In this case, I would not consider the  $\text{Sr}^{90}$  in whole wheat to be an undue hazard. If explosions producing appreciable fallout were to again take place, however, I would want to keep a close eye on  $\text{Sr}^{90}$  levels in food; and if high peak (not average) levels in whole wheat continued to occur, as I would expect would be true, then I would probably, with some reluctance, cut down my consumption of this food.

I must stress that this is a very personal evaluation. Other persons, studying the same data, might reach a quite different evaluation.

The point I wish to make is that the peak levels of fallout in food may be expected to have a major impact on people, and not just the average levels. This is likely to be true if the peak levels are distributed in such a way as to be possibly encountered by anyone in a large population.

This point is independent of the fact that for circumstances such as occurred in Japan in 1956, very large numbers of people may in fact be exposed to unusually high fallout levels as a result of a hotspot type of fallout.

6. The problem of who should set a "permissible level" for fallout is a major one. I have discussed this briefly in a letter which appears elsewhere, emphasizing that no scientific group can properly be expected to make very specific recommendations on this matter. In that letter I also give my own evaluation, with brief elaboration, that any appreciable further addition to present fallout levels would be legitimate cause for concern by very large numbers of people. It is clear that again such an evaluation is a very personal matter.

But one point here cannot be emphasized too strongly. That is, that ICRP or NCRP recommendations as to "acceptable levels" of radiation cannot properly be taken to apply to fallout, in any simple way. It appears to me that weighing of fallout effects from tests must be done on the basis of some kind of "worry level". It is likely that each individual studying the problem will reach a different conclusion as to what the worry level is. My own choice would be some not-large fraction of "natural background" dose rate—say 20 percent. Now past tests already will give  $\text{Sr}^{90}$  doses to human bone which will be at such a level for hundreds of millions of people. This is the basis for my conclusion that fallout levels from past tests are at about the worry point on a worldwide basis.

But the problem of deciding on the worry level for fallout is a problem of political decisions. In this country the appropriate body to make decisions regarding "acceptable" levels of fallout from nuclear tests is the Congress; and because of the complex technical data involved, the major responsibility for proper congressional decisions rests, I respectfully submit, on the Joint Committee on Atomic Energy.

(From the Washington Post and Times Herald, Sept. 7, 1959)

#### WEIGHING FALLOUT RISKS

Again this year, as in 1957, the congressional Joint Committee on Atomic Energy has tried to bring out the facts on nuclear fallout. As the committee has noted in its summary report, the evaluation of the effects of fallout from tests is very difficult, because of many uncertainties.

The fallout prediction in which I participated for the May hearings, on fallout from tests, reported numerical estimates of radiation dose which might be expected to result from past tests or the equivalent in future tests. This report did not attempt an evaluation of the seriousness or "permissibility" of the fallout levels discussed. Full discussion of these questions during the hearings was hoped for. But unfortunately there was not sufficient time.

I believe that study of the information brought out at the congressional hearings leads to two important conclusions. First, that any appreciable further addition to present fallout levels would be legitimate cause for concern by very large numbers of people—tens or hundreds of millions, both in the testing countries and throughout the rest of the world.

Second, that no "permissible" level for fallout can be drawn directly from recommendations of scientific groups; the decision as to whether any given amount of further fallout is tolerable must be made by the governments involved—in this country, the primary responsibility devolves on the Joint Committee on Atomic Energy.

I should like to give briefly some of the basis for the first conclusion. The strontium 90 intake in the average U.S. diet now contains appreciable contributions from foods other than milk. In fact, in 1958 more strontium 90 came from cereal products alone than from milk. This was true in spite of the fact that the average U.S. diet contains several times as much milk as cereal products, by weight; cereal products, however, had a several-times higher concentration of strontium 90 per pound.

For persons eating unusually large amounts of unusually radioactive food, therefore, bone levels of strontium 90 could be many times the U.S. average. If tests giving appreciable fallout are continued, exposure to unusually high fallout levels can be expected for large numbers of persons in the United States and for much larger numbers of persons—hundreds of millions—over the whole world.

I should make it clear that I do not believe fallout levels existing and expected from past tests constitute a grave hazard. But I do believe they are close to the point at which large numbers of people can be expected to be legitimately concerned about appreciable further fallout.

As to the question, "What constitutes a permissible or tolerable dose?" no scientific group can properly be expected to make very specific recommendations in the case of fallout. The problem is that whereas in the case of medical X-ray exposure, or industrial processes releasing radioactive material as a side effect, benefits can be weighed against deleterious effects, such a weighing cannot be done by scientists in the case of fallout.

It is useful to consider, for example, the numbers of people who might be injured by fallout if the very tentative recommendations of the National Committee on Radiation Protection for permissible exposure of large populations were to be applied in the case of fallout. The NCRP has tentatively recommended the continued use of a tenfold reduction factor to convert from occupational permissible levels to large-population permissible levels. If this procedure were to be applied in the case of strontium 90, one would obtain a 200-strontium-unit level as a large-population permissible dose.

Now 200 strontium units in the bones corresponds to a dose rate several times as high as the "natural background" dose rate. If natural background produces some 10 percent of leukemia and bone cancer cases (this is about the most pessimistic assumption that one can make, on the basis of present data), then a 200 strontium unit level might produce up to a 50-percent increase in these diseases. It seems very unlikely that a 50-percent increase would be considered acceptable by even the U.S. population. And it must be constantly kept in mind that hundreds of millions of people in the rest of the world receive more fallout exposure than the U.S. population.

It is clear therefore that one cannot easily apply a simple procedure such as a tenfold, or a thirtyfold, reduction factor from "occupational permissible levels," to obtain a meaningful "tolerable level" for fallout. The problem is one of political decisions. In this country the appropriate body to make decisions regarding acceptable levels of fallout from nuclear tests is the Congress; and because of the complex technical data involved, the major responsibility for proper congressional decisions rests with the Joint Committee on Atomic Energy.

W. SELOVE,  
University of Pennsylvania.

#### PHILADELPHIA.

(The writer is past chairman of the Radiation Hazards Committee of the Federation of American Scientists. He was a member of an advisory planning panel for the recent congressional hearing on fallout from nuclear tests.)

#### STATEMENT TO THE SUBCOMMITTEE ON FALLOUT PROBLEMS OF THE JOINT CONGRESSIONAL COMMITTEE ON ATOMIC ENERGY

(By Maurice B. Vischer, Ph. D., M.D., professor of physiology, University of Minnesota, chairman, Subcommittee on Biological Effects, Minnesota Governor's Committee on Atomic Energy Development Problems, May 4, 1959)

#### GENERAL SUMMARY

1. The setting of a maximum permissible dose standard for  $\text{Sr}^{90}$  in food without reference to either water content or to calcium content, as has just been done by the National Committee on Radiation Protection, leads to absurdities which make the standard meaningless under certain circumstances.

2. The raising of the maximum permissible body burden for  $\text{Sr}^{90}$  by the Committee operating under the auspices of the Department of Commerce seems to be astoundingly brash for two reasons: First, because the facts regarding human damage from low doses of  $\text{Sr}^{90}$  will not be known for another 10 or 20

years, since the induction period for carcinogenesis is that long; and second, because other serious students of the problem have recently given strong evidence that the permissible body burden should be lowered considerably.

3. More systematic studies of radionuclide content of all plant and animal food sources should be made promptly. More attention should also be paid to studies of the physiological control of levels of radionuclides in plant and animal metabolism.

4. Practical measures for removal of radionuclides from important food sources such as milk should be developed immediately. The principles for such removal are known. Only practical, large-scale processes need to be developed. Milk purification may be needed within a few years. If present maximum levels double, the hazard will be too great to accept.

5. The AEC has operated under the handicap of not having a biologist or medical scientist in its policymaking commission. If the AEC is to continue to have responsibility for health and biological protection, there should be such scientists appointed to the Commission.

#### 1. Fallacies in the maximum permissible concentration

In principle, a maximum permissible concentration of a noxious agent implies that below a certain concentration it is harmless, and that damaging effects are detectable at a threshold level. Furthermore, in the case of an agent that is stored in the body, it is assumed that one knows the stored dose which will cause damage, and the factors controlling its storage.

In the case of  $\text{Sr}^{90}$ , the National Committee on Radiation Protection has just announced a doubling of the stored dose which it considered to be a safe dose. This decision was taken within a few months after it became known that  $\text{Sr}^{90}$  levels in foods had risen sharply as a result of Russian and American bomb testing. There may be nothing but a coincidence in this relationship.

However, it is of some interest that recent workers outside this country—Engstrom, Hjernerstedt, Clemenson, and Nelson (Bone and Radiostrontium, Wiley, 1958)—have come to the opposite conclusion: namely, that the maximum permissible body burden should be lowered. They suggest a figure between 3 and 30  $\mu\text{g}$   $\text{Sr}^{90}$ /gm. Ca as opposed to the number 200  $\mu\text{g}$   $\text{Sr}^{90}$ /gm. Ca proposed by the U.S. Committee, working under the auspices of the Department of Commerce under Secretary Lewis Strauss, formerly Chairman of the U.S. Atomic Energy Commission.

The U.S. Committee has made another strange shift in its recommendations. This is to deal with  $\text{Sr}^{90}$  concentrations per unit of weight of food material, without reference to calcium content or water content. Presumably, a dried milk powder with more than 100  $\mu\text{g}$   $\text{Sr}^{90}$ /kg. would be unsafe, but the fresh milk from which it was made, having 10  $\mu\text{g}$ /kg., would be safe. The Committee could hardly mean this, but neither could they mean that 100  $\mu\text{g}$   $\text{Sr}^{90}$ /kg. of all food and drink would be tolerable if they would expect to hold the total body burden down to 200  $\mu\text{g}$   $\text{Sr}^{90}$  per gm. Ca, because the volumes of fluids ingested are highly variable—with the weather, with states of activity, etc.—and such a standard would be no standard at all.

An equally serious defect is that the new standard is unrelated to the level of calcium intake. A point about which there is no disagreement is that when there is a low calcium intake, a greater proportion of ingested  $\text{Sr}^{90}$  (as well as calcium) is stored in the bones than when the calcium intake is high. If a child were to live on plant foods containing 100  $\mu\text{g}$ /kg. (the present level in some plant materials) and this food contained 0.04 percent calcium, he would, if he took 1 kg. per day, ingest 36,500  $\mu\text{g}$   $\text{Sr}^{90}$  and 140 gms. Ca per year. At age 4 he would store 25 gms. Ca per year. If the discrimination factor against strontium is taken as 0.3 in the growing child, the new bone would contain about 75  $\mu\text{g}$   $\text{Sr}^{90}$ /gm. Ca.

If, on the other hand, the child's diet contained 0.1 percent calcium, and the same discrimination factor prevailed, the new bone would have only 30  $\mu\text{g}$   $\text{Sr}^{90}$ /gm. Ca. Even if the discrimination factor is not constant, the direction of the difference would be the same. The biological significance of  $\text{Sr}^{90}$  in food definitely depends upon the calcium content.

Thus, a maximum permissible concentration for radionuclides in foods without reference to water content and to calcium content is virtually meaningless.

The most serious action of the U.S. Committee has been to raise the suggested maximum permissible body burden. Their reasons for so doing appear incomprehensible in the face of the most obvious fact—namely that no one will



know what the real value for a "just detectable rise" in incidence of bone cancer and leukemia will be for at least 20 years—the induction period for carcinogenesis in man by bone seeking radionuclides in low doses.

## II. The levels of $Sr^{90}$ in wheat from the Great Plains region

The Minnesota Governor's Committee on Atomic Energy Development Problems collected samples of 1956, 1957, and 1958 wheat from University of Minnesota agricultural experiment stations and utilized the offer of the U.S. Atomic Energy Commission to analyze them. The data obtained appear in table I.

TABLE I.—Strontium 90 in wheat

| Location                 | $\mu\text{mc/gm. Ca}$ |      |       | $\mu\text{mc/kg. grain}$ |      |       |
|--------------------------|-----------------------|------|-------|--------------------------|------|-------|
|                          | 1956                  | 1957 | 1958  | 1956                     | 1957 | 1958  |
| Crookston.....           | 74                    | 606  | 213   | 16                       | 114  | 42    |
| Grand Rapids.....        | 88                    | 187  | 184   | 36                       | 61   | 40    |
| Rosemount.....           | 163                   | 130  | 124   | 77                       | 65   | 36    |
| Lamberton.....           | 160                   | 146  | 101   | 71                       | 51   | 37    |
| Waseca.....              | 94                    | 105  | 129   | 46                       | 47   | 40    |
| International Falls..... | 82                    | 124  | 120   | 28                       | 47   | 42    |
| Duluth.....              | 82                    | 111  | 111   | 28                       | 35   | 35    |
| Morris.....              | 82                    | 200  | ..... | 34                       | 80   | ..... |
| Means.....               | 107                   | 217  | 153   | 45                       | 66   | 42    |

Several points are noteworthy. First, it will be seen that the values range from as little as 74 to as much as 606  $\mu\text{mc/gm. Ca}$ , or from 16 to 114  $\mu\text{mc/kg. of}$  wheat. The highest value is above current NCRP standards for the MPC on a weight basis, and many of the values exceed the older MPC on the ratio to calcium basis. As noted in section I of this statement, the weight basis is not a satisfactory basis of evaluation of hazard because, if accepted, it could lead to total body burdens of an intolerable magnitude.

It is also to be noted that large local and/or temporal differences exist, and that therefore family consumption of homegrown products might provide greater sporadic hazards than would occur if the food ingested by a given family came from a wide variety of sources. In other words, consideration of radionuclide damage as a sporadic rather than simply as a universal phenomenon should be given serious attention. Nationwide or areawide average values or concentrations may be meaningless as far as individuals or small groups are concerned. According to Science (129, 1210, 1959), the AEC is currently spending only \$2.6 million per year on sampling and analysis in fallout studies. It would appear that this program could and should be enlarged at the expense of less urgent AEC work.

## III. Milk and bone

The Minnesota State Board of Health is engaged in a systematic monitoring program for milk. Table II presents results which it has reported.

TABLE II.— $Sr^{90}$  concentration milk in 1958<sup>1</sup>

|                        | $\mu\text{mc/liter}$ |         |          |
|------------------------|----------------------|---------|----------|
|                        | September            | October | November |
| Thief River Falls..... | 10                   | .....   | 14       |
| Duluth.....            | 24                   | 21      | .....    |
| Brainerd.....          | 23                   | .....   | 20       |
| Minneapolis.....       | .....                | 7       | 12       |
| Faribault.....         | .....                | 10      | 11       |

<sup>1</sup> From data released Feb. 11, 1960, by the State board of health (each value is for a pooled monthly sample obtained in these areas).

Aside from the fact that values above 20 c per liter were found in two cities, it is of interest to note that within a single State pooled daily samplings for a month showed more than a threefold spread in values. Obviously, when an aliquot from a pool of 30 daily samples from a milkshed shows a given value,

some of the constituent dairies must have had higher and others lower values. Some few dairy farms probably had as much as double the city average.

Prof. E. W. Pfeiffer of the School of Medicine of the University of North Dakota has provided me with analyses of human bone from subjects dying in mid-1958 from North Dakota, analyzed by the Lamont Laboratories and by Isotopes, Inc. The values are as follows:

| Age           | Bone            | $\mu\text{mc Sr}^{90}/\text{gm. Ca}$ | Laboratory |
|---------------|-----------------|--------------------------------------|------------|
| Fetus.....    | Total body..... | 1.05                                 | Lamont.    |
| Do.....       | do.....         | 54.63                                | Isotopes.  |
| Newborn.....  | do.....         | 0.53                                 | Lamont.    |
| 3 years.....  | Ribs.....       | 2.62                                 | Do.        |
| 61 years..... | Vertebrae.....  | .51                                  | Do.        |

It is to be anticipated that bone  $Sr^{90}$  levels will rise considerably in the coming years, even if nuclear explosions are stopped, both because of further fallout from stratospheric storage and because we have not yet come into equilibrium with existing soil burdens. Only when milk cattle have come into complete equilibrium with their plant food sources as to  $Sr^{90}/\text{Ca}$  ratios, will their milk come to maximum  $Sr^{90}$  values.

The present bone levels of  $Sr^{90}$  approach the lower limit set by Engstrom and others for possible carcinogenic effects. It is to be expected, therefore, that in the near future the general bone levels in children will pass the Engstrom threshold.

Since ion exchange systems of specific types are available for selective removal of ions, it would seem essential that practical processes be developed now for milk purification with respect to  $Sr^{90}$  on a commercial scale. If present milk  $Sr^{90}$  levels were to double, it would seem unduly hazardous to use milk without  $Sr^{90}$  removal.

## IV. General remarks

One difficulty in the operation of the AEC is that it has had no major spokesman for biological or medical science in the policymaking Commission. If the AEC is to continue to have responsibility for research and control in those areas, this defect should be remedied by having a competent general biologist (plant or animal) and a competent medical scientist as members of the Commission. It may, however, be that a better solution would be to divorce the promotion of utilization of nuclear energy from the biological and health problems entirely, and to turn the latter over to some more appropriate agency or agencies.

STATEMENT ON STRONTIUM 90 IN MINNESOTA WHEAT MADE BEFORE THE JOINT COMMITTEE ON ATOMIC ENERGY DURING THE AUTHORIZATION HEARINGS, FEBRUARY 27, 1959, BY WILLARD F. LIBBY, U.S. AEC

The  $Sr^{90}$  content of wheat is a matter of real concern to us. There is nothing good about radioactive fallout and it has been our constant effort to reduce it to the minimum in keeping with necessary weapons development programs. We welcome the interest of everyone willing to help us study it and have a system of publication and dissemination of the information which we hope is good. A particularly comprehensive document was issued recently. It is a nearly complete summary of U.S. data up till about last summer and is available through the Department of Commerce Office of Technical Services. It is the Health and Safety Laboratory Report No. 42 entitled, "Environmental Contamination From Weapons Tests."

The high levels found sometimes in wheat and rice and other grasses and vegetables apparently are due to a particular circumstance. These plants apparently pick up more fallout from the rain falling directly on the leaves than from the roots and the soil. As a consequence their level depends more on the rate of fallout than it does on the total accumulated fallout in the soil, though I hasten to add that there definitely is soil pickup. The soil pickup, however, does not lead to the large fluctuations with seasons of the year that is found in these grasses and lies at lower values than the peaks which direct leaf pickup can attain during a period of intense nuclear weapons testing when the rate

of fallout can be particularly high for a short time. In other words, a high value may be followed by lower values if the rate of fallout is lower during the later growing seasons due to the timing of nuclear tests.

We are very concerned, however, by the amount of  $Sr^{90}$  found in these products and by the fact that occasionally samples are found which exceed the levels which are generally acceptable for a steady diet. Actually, of course, the general average food level is the important matter and we can say that this level is well below the maximum permissible level as given by the NCRP.

To summarize, then, the high values in wheat probably are due largely to surface pickups from particular rains and are not expected to show a steady rise, except for the relatively smaller soil pickups, unless rates of testing exceeding the very heavy ones of last year occur again and I assure you that it is our policy to do everything to keep radioactive fallout outside the Nevada test areas to the very minimum.

It will be 2 years in June since your committee held its important hearings on radioactive fallout and we would be pleased to discuss the situation as it exists at present with you at any time you wish.

#### BACKGROUND ON STRONTIUM 90 IN WHEAT

Values for the "maximum permissible concentration" of a radioisotope in the human body are recommended by the National Committee on Radiation Protection and Measurements and the International Commission on Radiological Protection. Values for the maximum permissible concentration of a radioisotope in water ingested by a person are derived from the body values. The values for water are, in turn, roughly applied to food. The figure for strontium 90 in water is 800 micromicrocuries per kilogram of water for occupational exposure, and one-tenth of this amount, that is, 80, for so-called population exposure. The factor of one-tenth is based upon a recommendation of the ICRP. Both NCRP and ICRP recommended limits are based upon the further assumption of continuous intake at the permissible level. In applying the above values to food, it is assumed that the entire diet is taken into consideration.

It was pointed out in recent testimony before the Joint Congressional Committee on Atomic Energy that if only one food item is considered separately (which is a dubious procedure) it may be estimated that it would be necessary to eat at one sitting a few tons of wheat containing 80 micromicrocuries of strontium 90 per kilogram of wheat before a maximum permissible amount would accumu-

late in the body. While a person in the United States normally would eat several tons of wheat over a normal lifetime, he would not necessarily accumulate a maximum permissible amount of strontium 90 in his body, even if the wheat contained 80 micromicrocuries of strontium 90 per kilogram of wheat, because wheat is not the only food the person would have eaten. The body burden reflects the total diet. Much of the strontium is separated from the flour in the milling processes. This would increase the above estimates of a few tons by a factor of several fold if the flour only were eaten.

The Minnesota wheat samples showed an average strontium 90 content below the permissible level (23 samples taken over the years 1956-58 averaged 51 micromicrocuries of strontium 90 per kilogram of wheat). Only one sample showed above the permissible (this sample contained 113 micromicrocuries per kilogram of wheat). Such variations are to be expected. It is the average, not only for wheat but the entire diet, that counts. The present diet in the United States is roughly estimated to contain about 10 micromicrocuries per kilogram of food.

By far the best evidence of potential hazard comes from figures of actual concentration of strontium 90 in the human body itself. These figures are not estimates, but are actual measurements of the amount of strontium 90 in human bone, the part of the body where most of the strontium is deposited. The recommended maximum permissible concentration of strontium 90 in the human body is set at one-tenth microcurie for the general public by applying the factor of one-tenth to the occupational maximum permissible concentration of 1 microcurie recommended by the NCRP and the ICRP. The recommended limit for the general public is equivalent to 100 micromicrocuries of strontium 90 per gram of calcium on the assumption that the normal adult skeleton contains 1 kilogram of calcium. (Because the skeletons of children and adults differ widely as to weight but not as to calcium concentration, the concentration of strontium 90 in human bone is usually expressed in relation to the calcium content. The unit of concentration is 1 micromicrocurie of strontium 90 per gram of calcium.)

As of January 1958 the determined values for skeletal concentrations in North American children up to 1 year of age were between 0.46 and 1.84 concentration units, and for those from 1 to 4 years of age were between 1.23 and 1.53 concentration units. The worldwide average value for adults was 0.19 concentration units, while the corresponding value for all humans was 0.52 concentration units. These most recently available data indicate that by 1 year ago young children had accumulated up to 2 percent of the maximum permissible body burden of strontium 90 for the general population.

| Sample No. | Location            | Varieties (Spring Wheat)                                   | Year | Percent ash of weight received | d/m $Sr^{90}$ per g. ash | Percent Ca in ash | $\mu\text{Ci Sr}^{90}/\text{g. Ca}$ | $\mu\text{Ci Sr}^{90}/\text{kgm. whole wheat}$ |
|------------|---------------------|------------------------------------------------------------|------|--------------------------------|--------------------------|-------------------|-------------------------------------|------------------------------------------------|
| 1          | Rosemount           | Henry, Selkirk, Mida, Rushmore, Lee, and Thatcher          | 1956 | 1.93                           | 6.83±0.35                | 2.44              | 163                                 | 77                                             |
| 2          | Southwest           | Lee, Mida, Thatcher, Henry, Selkirk, and Rushmore          | 1956 | 2.07                           | 7.08±0.34                | 2.02              | 157                                 | 67                                             |
| 3          | Grand Rapids        | Lee, Mida, Rushmore, Thatcher, Selkirk, and Henry          | 1956 | 2.21                           | 6.20±0.47                | 2.04              | 141                                 | 77                                             |
| 4          | Morris              | Lee, Henry, Mida, Rushmore, Selkirk, and Conley            | 1956 | 2.00                           | 3.04±0.27                | 1.87              | 168                                 | 77                                             |
| 5          | Duluth              | Henry, Rushmore, Lee, Mida, and Thatcher                   | 1956 | 2.27                           | 3.74±0.28                | 2.04              | 81                                  | 28                                             |
| 6          | Crookston           | Henry, Rushmore, Lee, Mida, and Thatcher                   | 1956 | 1.53                           | 2.43±0.31                | 1.45              | 171                                 | 38                                             |
| 7          | Waseca              | Mida, Lee, Rushmore, Thatcher, Selkirk, and Henry          | 1956 | 2.07                           | 4.41±0.39                | 2.58              | 103                                 | 16                                             |
| 8          | North Minneapolis   | Lee, Selkirk, Henry, and Russell (Lee and Kenya Farmer)    | 1957 | 1.91                           | 5.31±0.38                | 1.84              | 124                                 | 47                                             |
| 9          | Rosemount           | Selkirk, Lee, and Thatcher                                 | 1957 | 2.26                           | 6.30±0.42                | 1.84              | 180                                 | 47                                             |
| 10         | Morris              | Thatcher                                                   | 1957 | 2.21                           | 7.11±0.46                | 1.84              | 184                                 | 47                                             |
| 11         | Grand Rapids        | Lee, Selkirk, and Russell (Lee and Kenya Farmer)           | 1957 | 2.06                           | 6.54±0.49                | 1.84              | 180                                 | 47                                             |
| 12         | Crookston           | Thatcher, Lee, Selkirk, and Conley                         | 1957 | 3.04                           | 6.73±0.42                | 1.54              | 205                                 | 63                                             |
| 13         | Southwest           | Thatcher, Selkirk, Lee (Lee and Kenya Farmer), and Russell | 1957 | 2.12                           | 5.38±0.33                | 1.84              | 180                                 | 63                                             |
| 14         | Waseca              | Thatcher, Selkirk, and Conley (Lee and Kenya Farmer)       | 1957 | 2.15                           | 4.28±0.31                | 1.84              | 180                                 | 63                                             |
| 15         | Duluth              | Selkirk and Russell                                        | 1958 | 1.84                           | 4.09±0.28                | 1.84              | 180                                 | 63                                             |
| 16         | Grand Rapids        | Varieties not known                                        | 1958 | 1.77                           | 7.52±0.35                | 1.84              | 180                                 | 63                                             |
| 17         | Rosemount           | Selkirk and Conley                                         | 1958 | 1.35                           | 5.88±0.32                | 2.13              | 124                                 | 60                                             |
| 18         | Unknown             | Russell, Mose                                              | 1958 | 1.70                           | 6.92±0.32                | 1.84              | 180                                 | 60                                             |
| 19         | Southwest           | Conley and Selkirk                                         | 1958 | 1.64                           | 4.44±0.24                | 1.84              | 180                                 | 60                                             |
| 20         | Unknown             | Conley, UFS                                                | 1958 | 2.05                           | 5.74±0.34                | 1.84              | 180                                 | 60                                             |
| 21         | Waseca              | Selkirk                                                    | 1958 | 1.84                           | 4.89±0.32                | 1.84              | 180                                 | 60                                             |
| 22         | Crookston           | Conley                                                     | 1958 | 2.00                           | 4.54±0.29                | 1.84              | 180                                 | 60                                             |
| 23         | International Falls | Unknown                                                    | 1958 | 1.96                           | 4.84±0.30                | 1.84              | 180                                 | 60                                             |

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## STRONTIUM-90 FALLOUT IN MINNESOTA

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Two and a half years ago a member of the Atomic Energy Commission pointed to the upper midwest as being the hottest spot with respect to radioactive fallout in the United States—if not in the world (1). Subsequent data suggest that this distinction undoubtedly belongs to areas closer to testing sites. Yet, Mandan, North Dakota, one of the few sites extensively studied in this area, has reported (2, 3a) the highest average levels of  $Sr^{90}$  in milk that have yet been published. The first substantial data relating to  $Sr^{90}$  concentrations in Minnesota foods have just been released. They are shown in Tables I and II.

Why the emphasis on  $Sr^{90}$ ? Chemically, fallout is a mixture of fission products, unexpended fuel elements, and a wide variety of induced activities—dozens of radioactive isotopes. In the first day or so after bomb detonation, isotopes of I, Nb, Zr, and Y are the major sources of radioactivity. A few weeks later, after the short-lived isotopes have largely disappeared, Ba, La, Pr, Ce, Nd, Ru and Rh nuclides are prominent. But over longer periods (1-100 years) it is the  $Sr^{90}$ - $Y^{90}$ ,  $Ca^{137}$ - $Ba^{137}$ , and  $Ce^{144}$ - $Pr^{144}$  mother-daughter pairs, the unexpended U and Pu, and the  $C^{14}$  created by neutron interaction with the atmospheric nitrogen that appear to be of greatest biological consequence.

TABLE I

 $Sr^{90}$  Concentration (in S.U.) in Minnesota Wheat\*

|                     | 1956 | 1957 | 1958 |
|---------------------|------|------|------|
| International Falls | —    | 124  | 120  |
| Crookston           | 74   | 606  | 213  |
| Grand Rapids        | 88   | 187  | 184  |
| Duluth              | 82   | —    | 111  |
| Morris              | 82   | 200  | —    |
| Rosemount           | 163  | 150  | 124  |
| Lamberton           | 169  | 146  | 191  |
| Waseca              | 94   | 105  | 129  |

\*From data released Feb. 6, 1959 by the Minnesota Atomic Development Problems Committee (each value represents a single sample).

TABLE II

 $Sr^{90}$  Concentration (in S.U.) in Minnesota Milk in 1958\*

|                   | Sept. | Oct. | Nov. |
|-------------------|-------|------|------|
| Thief River Falls | 10    | —    | 14   |
| Duluth            | 24    | 21   | —    |
| Brainerd          | 23    | —    | 20   |
| Minneapolis       | —     | 7    | 12   |
| Fairbault         | —     | 10   | 11   |

\*From data released Feb. 11, 1959 by the State Board of Health (each value represents the mean of a number of samples obtained in these general areas).

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Biochemically we know very little about most of these elements. Table III indicates the regions of the body in which some of these elements tend to be localized. This is important radiologically because it is at these points in the body that the direct damage would be expected to be centered. A number of these nuclides are bone-seekers, i.e., they are concentrated in the skeleton and remain fixed there for many years. Radiologically, the most dangerous among these may well be the unexpended fuel elements, U and Pu. Detailed information on these is lacking—perhaps because it relates directly to bomb efficiencies. Next comes  $\text{Sr}^{90}$ . Atmospheric  $\text{Sr}^{90}$ , like other fallout products, is swept down by rainfall. It lands on plants and soil, and is pictured as following the calcium cycle in nature. It enters the human body via foodstuffs. Of that retained, 99% is localized in the skeleton.

TABLE III

Hazardous Isotopes and Their Point of Attack in the Body

| Part of Body | Isotope                      |
|--------------|------------------------------|
| Skeleton     | Calcium—45                   |
|              | Strontium—89 and 90          |
|              | Yttrium—90 and 91            |
|              | Barium—140                   |
|              | Lanthanum—140                |
|              | Uranium and Plutonium        |
| Thyroid      | Iodine—131, 132, 133 and 135 |
| Liver        | Manganese—56                 |
|              | Cobalt—60                    |
|              | Cerium—141 and 144           |
|              | Praseodymium—143 and 144     |
|              | Neodymium—147                |
| Whole Body   | Cesium—137                   |
|              | Carbon—14                    |

Estimates of the biological hazard from radiation are based on three pools of knowledge. The first of these relates to experience with X-rays. Many of the early experimenters with X-rays died of cancer. As knowledge concerning cancer and other biological effects of radiation has increased, the levels of X-ray exposure that are considered to be tolerable or permissible have progressively decreased. For occupational exposure, this maximum permissible dose has declined from 50 roentgen units per year in 1931 to 15 r/yr in 1949 and finally to 5 r/yr

in 1957. The non-occupational maximum is taken to be 10% of this figure, or 0.5 r/yr.

The second source of information relates to experience with radium—a bone-seeking radioactive element. In the early part of this century, hundreds of radium dial painters were found to have radium in their skeletons. Additional thousands of people were fed or injected with radium salts by their physicians. A few are still alive and have been extensively studied. The main hazards from radioactive bone seekers, such as Ra, are anemia and leukemia (from irradiation of bone marrow), bone damage, and, at high Ra concentrations, bone cancer. On the basis of early estimates, the occupational maximum permissible body levels of Ra were set as 100 m $\mu$ c per person. Since  $\text{Sr}^{90}$  and its daughter released roughly 10-fold less ionizing energy per mole than  $\text{Ra}^{226}$  and its daughters, the corresponding  $\text{Sr}^{90}$  tolerance was 1000 m $\mu$ c per person. Assuming that a human skeleton contains 1000 g of Ca, this can be expressed as  $\approx 1 \text{ m}\mu\text{c Sr}^{90}/\text{g Ca} = 1000 \text{ uuc Sr}^{90}/\text{g Ca} = 1000 \text{ S.U.}$  (where 1 S.U. = 1 strontium unit or "sunshine unit" = 1 uuc  $\text{Sr}^{90}/\text{g Ca}$ ). Again, these maxima are being revised downward—presumably by the same 3-fold factor which changed the X-ray tolerances in 1957. According to present theory, at least, this would allow the bone-seeker tolerances to equal that skeletal isotope concentration which would set up a radiation intensity equal to the X-ray tolerance level. The matter is hardly this straight forward. The problem in this calculation, of course, is that Ra and other bone seekers tend not to be uniformly distributed throughout the skeleton. Hence, some spots are much "hotter" than others. However this matter is resolved, the population tolerances (again 10% of the occupational) will presumably be close to 30 uuc  $\text{Sr}^{90}/\text{g Ca}$  ( $\approx 30 \text{ S.U.}$ ), 3 uuc  $\text{Ra}^{226}/\text{g Ca}$ , or 1 uuc  $\text{Pu}^{239}/\text{g Ca}$ .

It is interesting to note at this point that both the occupational tolerances for X-rays and Ra were initially set for professional radiation workers who were assumed to be 45 year old males, and

were justified, in part, on the basis that it takes perhaps 25 years for many types of radiation damage to become evident. To quote NBS Handbook 52(4), "45 + 25 = 70 years, which is the average life span". It might be germane to point out that the average life span of the radiologist was 60.5 years—as compared with 65.7 years for other medical groups (5).

The third source of our knowledge relating to radiation hazards comes from information concerning levels of background radiation. We are constantly exposed to small amounts of radiation from which we cannot easily escape—cosmic rays,  $\text{C}^{14}$  and  $\text{K}^{40}$  in the body, and weak gamma radiation from earth, rock and structural materials about us. In Minnesota this background radiation amounts to about 0.1-0.2 r/year. In a few parts of the world it may range up to 0.4 r/year or so. This background radiation has been part of the human environment for countless generations, and must be accepted as a part of the normal hazard of living. By definition, any radiation dose which is small in comparison with this background must be considered to be of trivial biological importance. The maximum permissible dose of X-rays that has been set for the general population is 0.5 r/year. In comparison with background, this would seem a safe and reasonable level. It will probably never be practical to reduce it much below this level.

The relationship of the bone-seeker tolerances to background radiation cannot be so easily expressed. The calculations involved in relating  $\text{Sr}^{90}$  concentration (in S.U.) to radiation intensity (in roentgen units) at any point in the skeleton is neither simple nor certain. Engstrom and coworkers (6) have reviewed this matter in detail. The problem hinges about the facts that: (a) the beta radiation from  $\text{Sr}^{90}$  and  $\text{Y}^{90}$  have an average range of only 1-2 mm in bone, and (b)  $\text{Sr}^{90}$  is not homogeneously distributed through the bone mineral in the skeleton but tends rather to be laid down in discrete spots and layers. For example, it is known by direct analysis (8) that certain entire bones of the skeleton may have a  $\text{Sr}^{90}$  concentration that ex-

ceeds the skeletal average by 4-fold. Within these bones some points are much "hotter" than others. Thus any calculation relating to bone-seeker concentration (in S.U. or in uuc of isotope in the total skeleton) to radiation dosage (roentgen units per day delivered to the "hottest" point) must take into account a factor, N, which corrects for this degree of inhomogeneity.

In its 23rd Semiannual Report (9) the AEC ignores this factor in making its biological evaluations. It assumes that  $N = 1$ . This is known to be in error (8).

In the report of the Minnesota Atomic Development Committee (7), N is assumed to be about 6. This is a frequently used assumption because it allows agreement between the X-ray tolerance data and the tolerances estimated from Ra experience.

Engstrom (6) has recently pointed out that N is not constant but may range from 6 - 60 depending upon conditions, i.e., whether the  $\text{Sr}^{90}/\text{Ca}$  ratio in the diet is maintained constant throughout life or whether the  $\text{Sr}^{90}$  is administered in a single dose. At the present time the differential concentration factor is high (S.U. in average food is perhaps 100-fold higher than S.U. in average bone). If further contaminating processes were to cease today, it is estimated that by sometime in the 21st century  $\text{Sr}^{90}$  and calcium would be uniformly mixed in the biosphere—and the possibility of laying down highly variable concentrations of  $\text{Sr}^{90}$  in bone would be greatly decreased. The value of N that is appropriate for the evaluation of present day bone data must lie between 6 and 60. Some insist that public safety is best served by assuming the upper value in making safety estimates.

Table IV summarizes the above information and relates dose levels to biological effect. The importance of this discussion becomes apparent when one considers the biological significance of having, for example, 180 S.U. of  $\text{Sr}^{90}$  in the skeleton. The current AEC evaluation would estimate that 180 S.U. would produce a radiation intensity in bone of 0.45 r/yr which is below the maximum

permissible for the general population, and furnishes the skeleton with radiation only slightly above the natural background levels. Hence, it is "safe" and well below levels that might cause biological effect or should reasonably be termed a basis for concern. Using Engstrom's factor of  $N = 60$ , on the other hand, one would be led to say that 180 S.U. is about 60-fold above maximum permissible levels for the general population, and would double and perhaps triple a person's chances of having leukemia, and places him just above the threshold for bone damage.

This, briefly, describes the background of this problem faced by Subcommittee 2 of the National Committee on Radiation Protection and Measurement as it attempts to revise the maximum permissible levels for the bone-seekers. In the interim there is honest confusion. No single value can claim universal accept-

ance as defining the border between hazard and safety. According to AEC logic, the old maximum figure of 100 S.U. is overly conservative and should be raised to 200 S.U. At the other extreme a figure as low as 3 S.U. could be justified. There is an urgent need for more research, and for a dispassionate application of what we already know.

This discussion of population tolerances deals with skeletal levels of  $Sr^{90}$ . The data of Tables I and II concern food values of  $Sr^{90}$ . How are the two related? The answer requires the consideration of two additional factors: discrimination and diet.

Fortunately for us, the Ca appearing in newly formed bone carries with it less  $Sr^{90}$  than was present in the diet. This change in  $Sr^{90}/Ca$  ratio from food to skeleton is referred to as the discrimination factor. It is a variable factor, rang-

(Continued on Page 12)

TABLE IV

A Comparison of Three Estimates Relating Skeletal Strontium-90 Concentration to Radiation Dose

| Strontium Units in Total Skeleton<br>(1 S.U. = 1 $\mu$ c $Sr^{90}$ per g. of Ca) |                 |              | Equivalent<br>radiation<br>to "hottest"<br>point in r per<br>20 years | Biological Effect                                   |
|----------------------------------------------------------------------------------|-----------------|--------------|-----------------------------------------------------------------------|-----------------------------------------------------|
| AEC (9)                                                                          | Min. Report (7) | Engstrom (6) |                                                                       |                                                     |
| 50,000 S.U.                                                                      | 7,500 S.U.      | 750 S.U.     | 2,500                                                                 | Bone Cancer<br>Threshold <sup>a</sup>               |
| 10,000 S.U.                                                                      | 1,500 S.U.      | 150 S.U.     | 500                                                                   | Bone Damage <sup>a</sup>                            |
| 6,000 S.U.                                                                       | 900 S.U.        | 90 S.U.      | 300                                                                   | 50-100% increase in leukemia incidence <sup>b</sup> |
| 2,000 S.U.                                                                       | 300 S.U.        | 30 S.U.      | 100                                                                   | Max. Permissible <sup>c</sup> (occupational)        |
| 200 S.U.                                                                         | 30 S.U.         | 3 S.U.       | 10                                                                    | Max. Permissible <sup>c</sup> (population)          |
| 100 S.U.                                                                         | 15 S.U.         | 1.5 S.U.     | 5                                                                     | Equal to background radiation                       |

<sup>a</sup>— Bone cancer threshold is reportedly in the range 1,000 - 4,000 r of X-rays (Brit. J. Radiol. 26: 273-84 (1953) and Cancer 1: 3-29 (1948); 9: 528-42 (1956) and 10: 72-88 (1957)). From radium experience, bone damage appears at doses about 5-fold lower than the cancer-producing dose.

<sup>b</sup>— Calculated from data of Science 125: 965-72 (1957).

<sup>c</sup>— 5 r/yr (occupational) or 0.5 r/yr (population) and the corresponding  $Sr^{90}$  concentrations that can be calculated (using  $N = 1, 6$  or  $60$ ) to produce equivalent radiation intensities.

ing normally from 2 to 8. The adult is not actively building a skeleton, but does exchange perhaps 7% of his skeletal Ca per year. This exchange reaction is fairly selective in discrimination against Sr. Hence the Sr/Ca ratio in food may be 2-8 times greater than in the skeleton. New formation of bone by children apparently does not show this same degree of selectivity (15), so that the discrimination factor in this case is closer to 2. In certain pathological states the discrimination may actually be reversed (10). In a general way one can say that the  $Sr^{90}$  concentration in food is perhaps 2-fold (children) to 4-fold (adults) greater than the  $Sr^{90}$  concentration appearing in newly acquired skeletal calcium.

course of the past few years. The dietary averages have been calculated on the basis of census report figures (13) which indicate that the average American obtains 80-85% of his dietary calcium from milk and milk products, perhaps 15% from plant sources, and some 1-3% from meat products. This immediately indicates the central importance of milk in this evaluation.

The dietary levels of  $Sr^{90}$  have increased sharply in the past 5 years. There is a variation in average levels of perhaps 2-fold as one goes from north to south within the state. At worst, they are still not as high as some reported from North Dakota (2).

How does one evaluate these data with

TABLE V

The  $Sr^{90}$  Concentration (in S.U.) in an Average Diet as Estimated from Food Sources

|        | Food Sources |             |                   | Average<br>$Sr^{90}$ in<br>Diet |
|--------|--------------|-------------|-------------------|---------------------------------|
|        | Milk         | Plants      | Meat <sup>a</sup> |                                 |
| 1954   | 1 (0.5-1.5)  | 5 (2-15)    | 6 (1-19)          | 2                               |
| 1955   | 5 (1-10)     | 28 (6-53)   | 27 (4-183)        | 8                               |
| 1956   | 6 (2-17)     | 76 (1-2180) | 44 (8-170)        | 15                              |
| 1957-8 | 15**         | 185**       |                   | 41                              |

<sup>a</sup>From analysis of animal bone.

\*\*Average of data in Tables I and II.

Discrimination also occurs in the cow and at other points in nature (11). This is the explanation given for the marked differences in the levels of  $Sr^{90}$  in the different foods listed in Tables I, II and V. As discrimination may vary from person to person, so also may the eating habit patterns vary. From Table V it appears that a vegetarian who eschews milk and milk products may have a distinctly higher  $Sr^{90}$  intake than the average.

Surveys (8) indicate that there are indeed very large between-individual variations in skeletal  $Sr^{90}$  levels. Within any one area and any one age group these values may vary over a 10- to 50-fold range. Such variations must be taken into account in any evaluation of average values (12).

In Table V an attempt is made to estimate from available data the concentration of  $Sr^{90}$  which has accompanied the dietary calcium over the

respect to safety-taking discrimination, individual variation, etc. into account? Clearly they are high enough so that no one can say with assurance that these levels are safe. Nor can one point to any given child and say with assurance that he will develop bone cancer 20 years from now. The averages fall in that very broad twilight area defined by our uncertainties and lack of knowledge in this field. The upper portion of the estimated range for skeletal  $Sr^{90}$  levels in children, at least in parts of this state, is cause for concern by any reasonable tolerance standard. Levels are still rising, and it has been suggested that they will continue to rise for the next 10-20 years (14).

Thought is being given to the problems of confiscating radioactive foods (16). As time goes on actions will be taken that will have exceedingly important economic and political consequences on one hand and health significance on

the other. A firm understanding of these matters by the technically trained individuals in the population can do much to stabilize public thought on these matters and assure intelligent support of measures required to control this situation.

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CONGRESS OF THE UNITED STATES,  
JOINT COMMITTEE ON ATOMIC ENERGY,  
April 7, 1959.

Mr. A. R. LUEDECKE,  
General Manager, U.S. Atomic Energy Commission,  
Washington, D.C.

DEAR MR. LUEDECKE: Attached for review and comment by the Commission staff is a copy of an article by E. W. Pfeiffer, entitled "Some Aspects of Radioactive Fallout in North Dakota," which appeared in the autumn 1958 issue of the *North Dakota Quarterly*.

In connection with the studies of the fallout situation in North Dakota it would be appreciated if you could provide the Joint Committee with information as to the status of the analysis of human bone specimens from North Dakota which we understand is being carried on under AEC sponsorship. We have been informed that a study has been underway at the Lamont Geological Laboratory of Columbia for almost a year but that no report has been given.

It would be appreciated if the Commission will investigate the circumstances of the apparent delay in obtaining reports on North Dakota bone specimens and what the current situation is with respect to fallout in North Dakota.

Sincerely yours,

JAMES T. RAMEY,  
Executive Director.

[From the *North Dakota Quarterly*, autumn, 1958]

## SOME ASPECTS OF RADIOACTIVE FALLOUT IN NORTH DAKOTA

(By E. W. Pfeiffer)

On December 30, 1958, in Washington, D.C., the Council of the American Association for the Advancement of Science passed the following resolution: "It is our further task to help in the transmission and translation of this knowledge [of the effects of radiation] to the public, for the final and effective decisions on nuclear control must be made not by scientists alone, nor by the military, but by all citizens—" *Science*, **129** (Jan 16, 1959) 136-137.

## INTRODUCTION

In May 1958 the Grand Forks Herald reported that, as a result of the relatively high levels of strontium 90 ( $Sr^{90}$ ) in powdered milk processed at Mandan, N. Dak., human bone samples from North Dakota were to be analyzed for their  $Sr^{90}$  content. Subsequently, the Minneapolis Tribune revealed that, in addition to analysis of milk, analyses had been made of North Dakota soil, air, river water, grain, and animal bone. According to the Minneapolis Tribune, the study was "to be kept off the record." However, it is difficult to understand how the people of North Dakota can intelligently express their opinions on the vital question of continuation of nuclear weapons tests (as they were asked to do in the 1956 presidential campaign) if they do not have information concerning the results of these tests. The following paper, therefore, presents "for the record" some of the results of the tests which have been conducted on radioactivity from fallout in North Dakota.

Since I am not competent in the field of radiobiology or nuclear physics, I shall not consider the implications of the data presented below, other than to relate them to certain concepts of authorities on radioactive fallout, and to compare them to official maximum permissible concentrations. I wish to express my gratitude to the Health and Safety Laboratory and the Division of Biology and Medicine of the U.S. Atomic Energy Commission, the U.S. Weather Bureau, and the U.S. Public Health Service for their generous cooperation in making the following material available to me. I am also grateful to Senators William Langer and Hubert H. Humphrey for their invaluable assistance in obtaining data.

## PRESENTATION OF DATA

Figure 1 presents, in graphic form, the levels of  $Sr^{90}$  in fallout and in milk as they have occurred in different areas of North and South Dakota during parts of 1957 and 1958. The curve for  $Sr^{90}$  in milk processed at Mandan shows that a peak of almost 33 strontium units (micromicrocuries  $Sr^{90}$  gram of calcium) was

reached in August 1957. This was the highest level reported for any of the 30 stations of the AEC throughout the world. This situation raises the question as to just why  $\text{Sr}^{90}$  in North Dakota milk should be higher than in that from Utah, for example, which is much closer to the Nevada test site of the AEC than is North Dakota.

Measurements of the day-by-day fallout of  $\text{Sr}^{90}$  in North Dakota during the summer of 1957 suggest a possible reason for the sudden rise of  $\text{Sr}^{90}$  in the August milk. It should be recalled that during the summer of 1957 Operation Plumbbob was carried out at the Nevada test site, and many nuclear weapons were exploded. Figure 1 shows that there was a very great increase in  $\text{Sr}^{90}$  deposition during July at the Fargo sampling station, and a substantial increase at the Williston station. Radioactivity from  $\text{Sr}^{90}$  at Fargo rose from a little over 2 millicuries per square mile in June to over 26 millicuries per square mile in July, and then returned to about 2 in August. This was a much higher level of radioactivity than that which occurred at Vermillion, S. Dak. (fig. 1), and was as much as the total  $\text{Sr}^{90}$  deposition accumulated in many other areas from the beginning of nuclear weapons test to 1957 (table I).

FIG. 1 —  $\text{Sr}^{90}$ : North Dakota Fallout and Incidence in Milk  
(Prepublication Report, Health and Safety Lab., USAEC.)

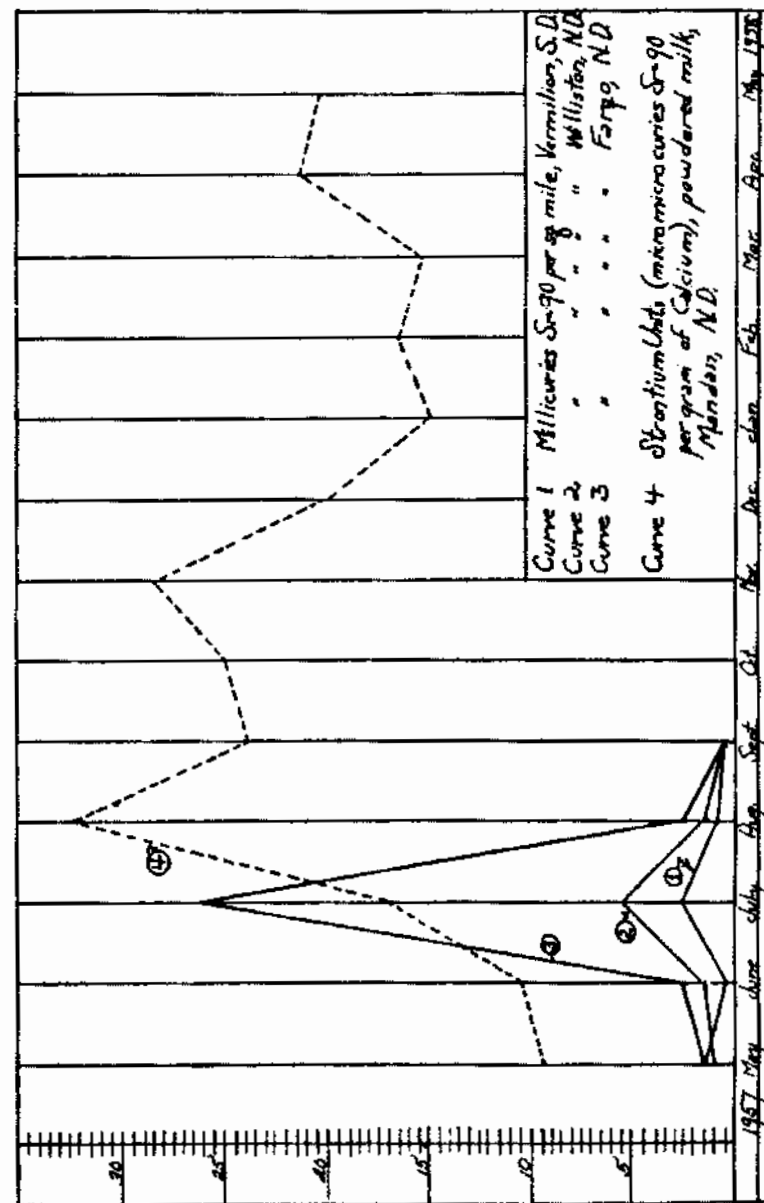


FIG. 2 — Sr-90: Fallout and Precipitation, North Dakota  
(Prepublication Report, Health and Safety Lab., USAEC.)  
(Only fallout above 0.2 millicuries/sq. mile is graphed)

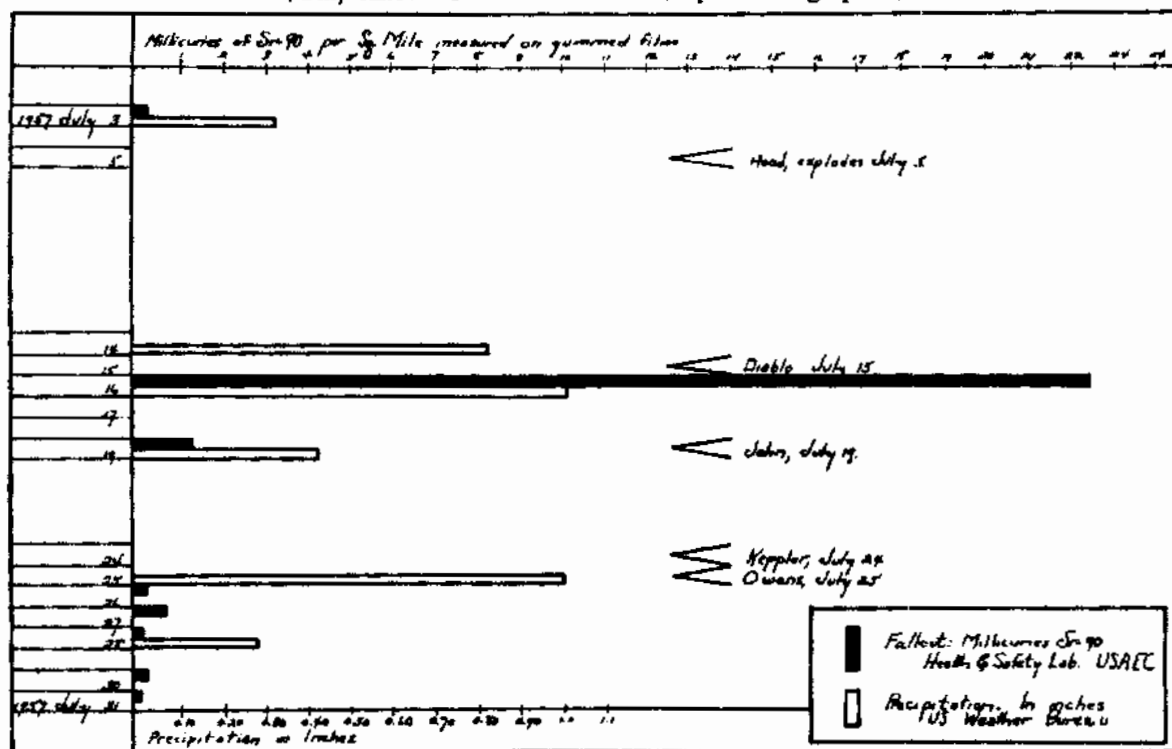
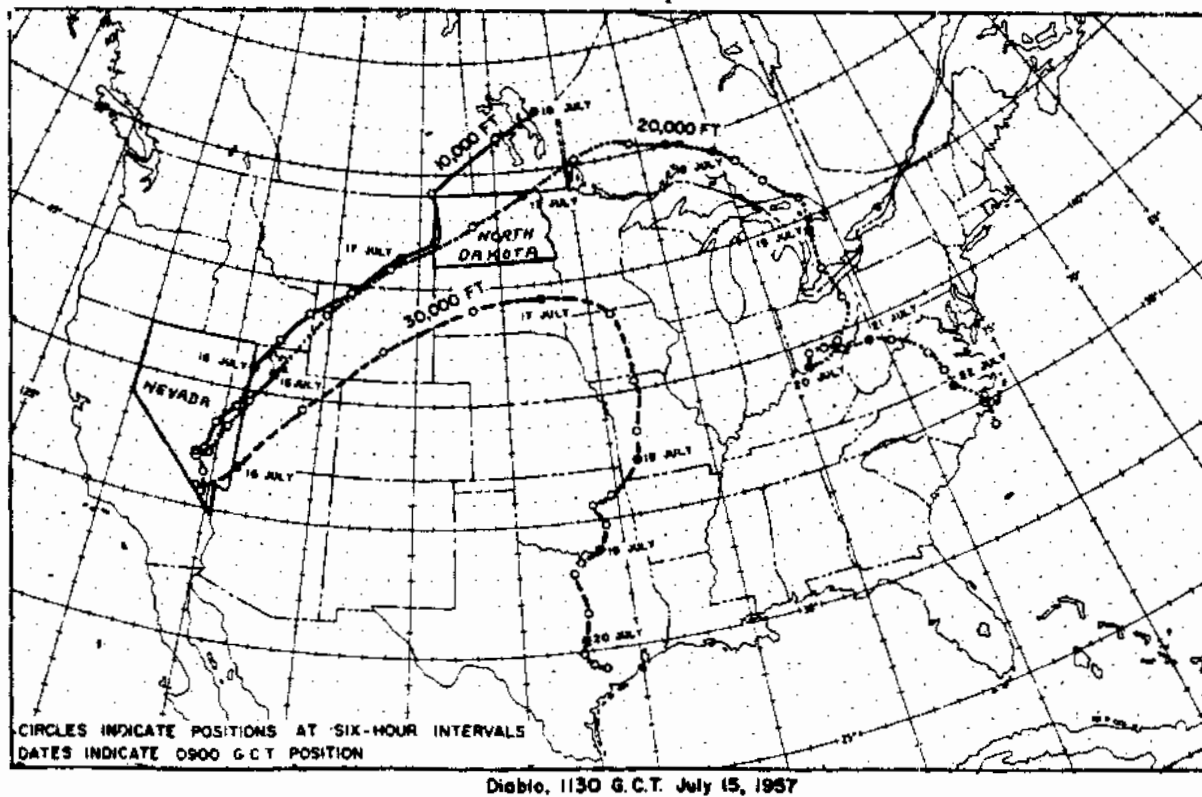


FIG. 3 — U. S. Weather Bureau Report on Diablo Movements



According to the daily July measurements of  $\text{Sr}^{90}$  deposited at Fargo (fig. 2) almost all of the  $\text{Sr}^{90}$  fell on July 16. Figure 2 also shows that on July 15 a nuclear weapon with the code name "Diablo" was detonated. Its radioactive cloud, as charted by the U.S. Weather Bureau, subsequently moved over North Dakota, as shown in figure 3. This was the case for all of the clouds from the July shots, but in September the clouds passed far to the south and  $\text{Sr}^{90}$  deposition at Fargo was correspondingly small during this month. While the radioactive cloud was presumably in this area, there was heavy precipitation, and this is correlated with  $\text{Sr}^{90}$  deposition in figure 2. The correlation suggests this hypothesis: radioactive debris, including  $\text{Sr}^{90}$  from Diablo was blown from the Nevada test site to the north-central area of the United States, where the  $\text{Sr}^{90}$  was washed out by heavy local precipitation. Libby (1) states, "The efficiency with which rain removes fallout from the air through which it passes is probably high." He also states: "We conclude that total fallout in arid regions should be appreciably lower than in areas with normal rainfall. This effect seems to be borne out by the data available now, though more definitive experiments are needed." Since the areas to the west of North Dakota have little precipitation during July, it can be assumed that the radioactive clouds arrived in North Dakota with a full load of debris, much of which may have been washed out by the local heavy precipitation in the Fargo area and elsewhere.

TABLE 1

## 1.1 Strontium 90 in milk near Mandan, N. Dak. (9)

| Location            | Sampling date | Strontium units (micro-microcuries $\text{Sr}^{90}$ gr. Ca) |
|---------------------|---------------|-------------------------------------------------------------|
| South Soo.....      | May 1956..... | 21.27                                                       |
| West of Mandan..... | do.....       | 11.16                                                       |
| McLoughlin.....     | do.....       | 8.70                                                        |
| North Soo.....      | do.....       | 35.81                                                       |
| South Branch.....   | do.....       | 18.62                                                       |
| (Average).....      |               | 19.06                                                       |

## 1.2 Strontium 90 in hay

| Location            | Sampling date   | Strontium units |
|---------------------|-----------------|-----------------|
| Mandan, N. Dak..... | June 1956.....  | 39.0            |
|                     | July 1956.....  | 27.0            |
|                     | do.....         | 21.0            |
| Ithaca, N. Y.....   | June 1956.....  | 36.0            |
| Tifton, Ga.....     | Sept. 1956..... | 120.0           |

## 1.3 Strontium 90 in animal bone

| Location            | Sampling date  | Strontium units |
|---------------------|----------------|-----------------|
| Mandan, N. Dak..... | Mar. 1956..... | 24.0            |
|                     | May 1957.....  | 26.8            |
| Logan, Utah.....    | Nov. 1956..... | 5.3             |
| Tifton, Ga.....     | Oct. 1956..... | 18.9            |

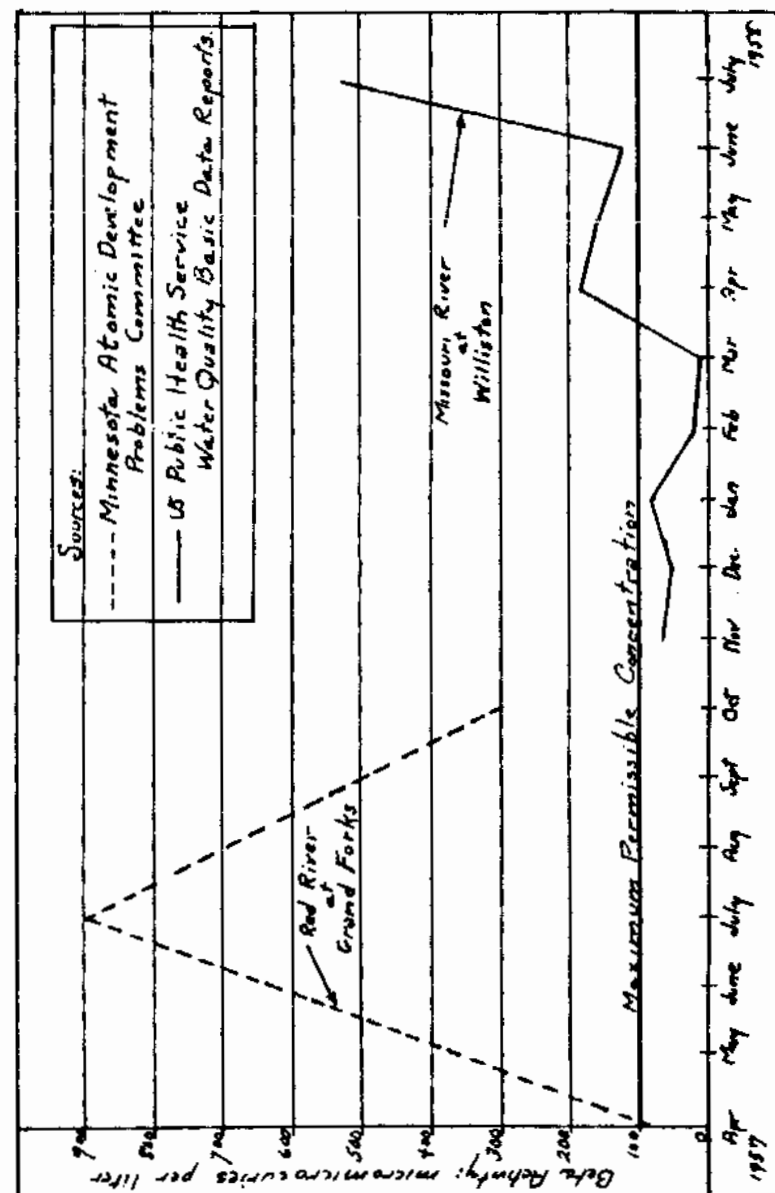
## 1.4 Strontium 90 in soil

| Location            | Sampling date   | Millicuries/square mile |
|---------------------|-----------------|-------------------------|
| Mandan, N. Dak..... | Aug. 1956.....  | 10.10                   |
| Logan, Utah.....    | Sept. 1956..... | 5.06                    |
| Ithaca, N. Y.....   | Dec. 1956.....  | 13.70                   |

## 1.5 Cumulative deposition of strontium 90 to June 1957

| Location                  | Millicuries/square mile |
|---------------------------|-------------------------|
| Minneapolis, Minn.....    | 25.0                    |
| San Francisco, Calif..... | 14.0                    |
| Rapid City, S. Dak.....   | 18.0                    |
| Las Vegas, Nev.....       | 23.0                    |

FIG. 4—Radioactivity of North Dakota Rivers





Such a heavy deposition of  $\text{Sr}^{90}$  as occurred at Fargo on July 10 might account for the high level in August milk in the following ways: the  $\text{Sr}^{90}$  moves into the soil where it is picked up by the roots of plants and incorporated into their foliage, which is then eaten by cattle. Thus some of the  $\text{Sr}^{90}$  moves from plant to milk. Moreover,  $\text{Sr}^{90}$  is deposited directly on the foliage that the cattle eat, thus bypassing the soil. In view of these relationships of  $\text{Sr}^{90}$  in soil to  $\text{Sr}^{90}$  in plants, bone, and milk, it is important to know the amount of  $\text{Sr}^{90}$  in the soil and vegetation where dairy cattle are grazing. The AEC has carried out a very small program in North Dakota to "study the uptake of  $\text{Sr}^{90}$  from soil to plants to animal bone." Table I gives pertinent data resulting from this study. It is interesting to note that although the hay and soil  $\text{Sr}^{90}$  are not high, the high level of animal bone is "what might be expected from the high level in the milk" (2). This suggests that the source of much of the  $\text{Sr}^{90}$  found in North Dakota milk is direct fallout upon leaves which are then eaten by the cattle.

This interpretation is consistent with the concept of Libby (1) who states: "The bypassing of soil entirely, which occurs in the direct fallout on plant surfaces, of course means that the retarding effects of high Ca contents in soil are inoperative, and cattle grazing on such foliage may show little correlation in the  $\text{Sr}^{90}$  contents with the soil  $\text{Sr}^{90}$  activity for this reason. This appears \* \* \* to be true in the U.S. Midwest." Another source of  $\text{Sr}^{90}$  entry into cows is dust, as a recent report points out: " \* \* \* grazing animals inhale appreciable quantities of surface dust containing  $\text{Sr}^{90}$ " (9).

Correlated with the high  $\text{Sr}^{90}$  in fallout, as measured by gummed films, is the rise in total beta radioactivity of Minnesota rivers during the summer of 1957 (3). Figure 4 shows that during the summer of 1957 the beta radioactivity of the Red River at Grand Forks rose many times higher than that recorded during the previous April, or subsequent October.

#### DISCUSSION

It seems appropriate to briefly review the particular biological significance of  $\text{Sr}^{90}$  and then compare the levels of radioactivity in North Dakota with recent ideas of experts about maximum permissible concentrations of radioactive materials. According to Libby (1): "Strontium 90 is of particular importance among the fission products because of chemical and physical characteristics which result in a comparatively high retention in the skeleton. These are chemical similarity to Ca, an element essential to both plants and animals; an average life of about 40 years; and a low rate of elimination from the skeleton."

Furthermore,  $\text{Sr}^{90}$  in the environment has apparently caused bone cancer in at least one wild animal, (4) and is being studied as a possible cause of leukemia. The present maximum permissible concentration for human populations not engaged in radioactive work is 100 strontium units. Since the average level of  $\text{Sr}^{90}$  in the milk processed at Mandan has been approximately 20 strontium units for the year June 1957 through May 1958, one might expect to find bone levels as high as 20 strontium units in some very young North Dakota children, because according to Libby (1) "children seem to carry  $\text{Sr}^{90}$  approximately equal to the average level of the milk during their lives." This is one-fifth the present maximum permissible concentration, but there is a possibility that this maximum may be lowered. Swedish Government experts (5) suggest a maximum permissible concentration about one-tenth of the present, or 10 strontium units. The British Medical Research Council (7) also supports a lowered maximum permissible concentration.

There is the possibility that very young children on certain farms of the upper Midwest who drink only local milk may now have  $\text{Sr}^{90}$  bone burdens

<sup>1</sup> A very recent report (9) reveals that in August 1958 the  $\text{Sr}^{90}$  in soil near Mandan had risen to over 46 millicuries/square mile.

<sup>2</sup> On Feb. 6, 1958, the Minnesota Atomic Development Problems Committee reported that samples of wheat grown in the upper Midwest during the years 1956, 1957, and 1958 show radioactivity in excess of the permissible level of 100 strontium units in food intake. A maximum of 606 strontium units was found in one of the samples. (One wonders if the records of the Government show that the prevailing winds and the fact that the Midwest feeds the Nation were duly considered when the site and the nature of atomic tests were decided upon.—Ed.)

which are higher than those indicated by average milk levels, because these averages are derived from pooled milk samples. In this connection, the U.S. Public Health Service states (8): "It is our belief that there may be variations in  $\text{Sr}^{90}$  within relatively small areas \* \* \*." Data in a recent report (9) show that milk from five areas near Mandan, tested in May 1958, varied from 8.7 to 35.8 strontium units, with an average of 19 strontium units (table 1).

In view of the uncertainty regarding current maximum permissible concentrations, the results of the North Dakota human bone analyses now being carried on at Lamont Geological Laboratory of Columbia University will be of the utmost significance for the people of North Dakota.

Concerning radioactivity in water, the National Bureau of Standards, Handbook 52, gives the maximum level of beta radioactivity for drinking water as 100 micromicrocuries per liter, stating this value "is believed to be safe for exposure to any of the isotopes for periods of a few months." Data contained in a Minnesota official report (3) show that certain rivers in Minnesota and the Red River have shown radioactivity above this maximum for a considerable period.

#### CONCLUSIONS

The material presented in this paper suggests the need for continuing and increasing studies of radioactive fallout in North Dakota, and for interpretation of the North Dakota data by experts in the field of radiobiology, meteorology, and nuclear physics. A recent paper by leading authorities on radioactive fallout (6) summarizes the present situation:

"The problems of widespread, low-level radioactive contamination from nuclear weapons testing have been increasingly before the public during the past year. The principal concern is the fallout and entry into the biosphere of strontium 90. There is general agreement that present levels of strontium 90 in food-stuffs and in the human body are far below the most conservative permissible amounts; however, the human strontium 90 burden may be expected to rise as a result of deposition of stratospheric debris from weapons already (and subsequently to be) tested. Predictions based on conservative assumptions indicate that there remains a considerable margin of safety. If the rate of weapons testing continues to increase, however, this margin may eventually disappear. Although the permissible levels contain inherent safety factors, it is essential that close attention be devoted to all aspects of the fallout problem during the next several years. Only in this way can advance notice of the possible approach to permissible levels be obtained and assurance given that they will not be exceeded inadvertently."

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ATOMIC ENERGY COMMISSION,  
Washington, D.C., May 13, 1959.

Mr. JAMES T. RAMEY,  
Executive Director, Joint Committee on Atomic Energy,  
Congress of the United States.

DEAR MR. RAMEY: In reply to your letter of April 7, 1959, to General Manager Lueddecke, we are glad to provide the following information on the current situation with respect to fallout in North Dakota and, specifically, on the human bone samples received last year by Lamont Geological Observatory for analysis. We have also received for comment by members of our staff, as requested, the article by E. W. Pfeiffer which appeared in the autumn 1958 issue of *The North Dakota Quarterly*. A copy of the comments is attached.

The delay in analysis of the human bone samples from North Dakota held by the Lamont Geological Observatory was due to the following circumstances beyond the control of Lamont. It has been the policy of the Atomic Energy Commission for more than 5 years to send as many of its fallout samples as practical to commercial laboratories for analysis. At the time the North Dakota samples were received, the AEC had contracts with the three leading commercial laboratories in this field, all of whom had demonstrated on test samples their ability to make analyses with acceptable accuracy. However, despite longstanding efforts to raise standards of routine performance of these laboratories, cross-checks between laboratories and the submission of blind duplicates to the same laboratories demonstrated that none of these laboratories were exercising adequate quality control. In addition, two of the laboratories were overextended and were unable to meet their schedules. As a result, it became necessary to greatly reduce the number of samples sent to these laboratories pending the institution of adequate corrective measures. Both the Lamont Laboratory and our Health and Safety Laboratory at New York have made every effort to perform the most urgent analyses on an emergency basis, but we still have a large backlog of samples which under normal conditions would have been analyzed during the past year.

The bones samples to which your letter refers were among those deferred. Of the 12 samples originally submitted from North Dakota, Lamont has recently completed the analysis of 4. A copy of their report is attached. Copies have been sent also to Dr. Pfeiffer and, in view of their expressed interest, Senators Humphrey and Langer. Meanwhile, four more samples have been received for analysis.

As described in the article by Dr. Pfeiffer, fallout in North Dakota during the past 2 years has been relatively high. Measured concentrations of strontium 90 in soil at Mandan, N. Dak., increased from about 10 mc/sq. mile in 1956 to about 19 mc/sq. mile in 1957 and about 45 mc/sq. mile in 1958, while the annual average concentration in samples of milk from Mandan increased from about 9 uuc/gm Ca in 1956 to about 18.4 uuc/gm Ca in 1957 and 20.5 uuc/gm Ca in 1958.

The four bone samples which have been analyzed represent too small a sample to provide a reliable indication of human uptake in this area. This is particularly true since two of them were fetal and one from a 61-year-old adult. The best indication is from a 3-year-old child who died in mid-1958. This concentration of 2.62 uuc Sr<sup>90</sup>/gm Ca, while about 30 percent higher than the average of values observed in young children from other areas, is smaller than might be expected in this area.

If I can be of further assistance, please do not hesitate to let me know.

Sincerely yours,

FORREST WESTERN  
(For Charles L. Dunham, M.D., Director,  
Division of Biology and Medicine).

STAFF COMMENTS ON PAPER BY E. W. PFEIFFER, "SOME ASPECTS OF RADIOACTIVE FALLOUT IN NORTH DAKOTA," *THE NORTH DAKOTA QUARTERLY*, AUTUMN, 1958

The data presented on pages 93 to 97 of the articles are as factual as available data permit. It may be noted that table 1 which compares concentrations of strontium 90 in soil, feed and animal bone in 1956 gives concentrations in milk in 1958. For comparison the average concentrations measured in milk from Mandan during 1956 was 92 $\mu$ c/liter.

The statement that " \* \* \* Sr<sup>90</sup> in the environment has apparently caused bone cancer in at least one wild animal," made in the second paragraph of the discussion on page 98 is irrelevant, if not misleading, since it refers to a muskrat which lived at the edge of a basin used to remove radioactivity from a small stream flowing on land owned and controlled by the AEC. Concentrations of strontium 90 in the bottom of the basin were from 10,000 to 100,000 times as high as any which have resulted in soil from fallout, and concentrations in the skeleton of the muskrat were far higher than those found to produce bone cancer in experimental animals. It seems unlikely that concentrations of strontium 90 in the bones of children will be as high as in the milk they drink. Observed skeletal concentrations in children have been about one-fourth those in milk. The single bone sample from a young child in North Dakota analyzed thus far contained a smaller concentration of strontium 90 than might have been expected on this basis. However, normal variation from one individual to another is too great to draw any conclusion from a single sample.

The "maximum level of beta radioactivity for drinking water" referred to by Dr. Pfeiffer is recommended for use when the composition of the radioactivity is totally unknown and is not applicable to fallout as it occurs in rainwater and drainage systems. It is, in fact, based on the assumption that the activity is almost entirely due to strontium 90, the only beta emitter listed in Handbook 52 with a maximum permissible concentration in water as low as 100 micromicrocuries per liter. Numerous radiochemical analyses of strontium 90 in rainwater and rivers indicate that generally less than 1 or 2 percent of the total activity is due to strontium 90.

Concentrations of Sr<sup>90</sup> in human bones from North Dakota

| Lamont No. | Age      | Sex    | Bone       | gms ash | Total Ca | Total Sr <sup>90</sup> | S. U.<br>(uuc Sr <sup>90</sup> /gm Ca) |
|------------|----------|--------|------------|---------|----------|------------------------|----------------------------------------|
| L-7470     | Newborn  | Female | Total body | 5.75    | 2.06     | 2.42 $\pm$ .30         | .53 $\pm$ .06                          |
| L-7471     | 61 years | Male   | Vertebrae  | 2.95    | 1.08     | 1.22 $\pm$ .11         | .51 $\pm$ .04                          |
| L-7472     | Fetus    | Male   | Total body | 7.13    | 2.25     | 5.22 $\pm$ .32         | 1.06 $\pm$ .05                         |
| L-7478     | 3 years  | Male   | Ribs       | 7.73    | 2.04     | 16.90 $\pm$ .35        | 2.62 $\pm$ .05                         |

NOTE.—Date of death for these samples was about mid-1958.

A STATEMENT BY THE GREATER ST. LOUIS COMMITTEE FOR NUCLEAR INFORMATION ON THE STRONTIUM 90 CONTENT OF MILK, PREPARED AT THE REQUEST OF THE ST. LOUIS DAIRY COUNCIL, JANUARY 26, 1959

Recent analyses, which show that milk in the St. Louis area contains more strontium 90 than is found in milk from other tested areas, is causing some public concern. Believing that such concern can only be met by an accurate statement of facts, the St. Louis Dairy Council has requested the Greater St. Louis Committee for Nuclear Information to prepare a statement about this problem. The committee for nuclear information is an organization devoted to the collection and dissemination of information on nuclear matters. The statement was prepared for the committee for nuclear information by three of its members, Dr. Walter C. Bauer, instructor in surgical pathology at the Washington University School of Medicine; Dr. Barry Commoner, professor of plant physiology at Washington University; and Dr. Eric Reiss, assistant professor of medicine and preventive medicine at the Washington University School of Medicine, in consultation with Dr. James Kling, director of the Department of Pediatrics, St. Louis University School of Medicine; Dr. William G. Klingberg, associate professor of pediatrics at the Washington University School of Medicine; Dr. Walter Schlesinger, director of the Department of Microbiology, St. Louis University School of Medicine; and Dr. Park J. White, director of pediatric service at the Homer G. Phillips Hospital. The statement follows:

"Strontium 90, a radioactive substance produced by atomic explosions, has been falling on the earth since 1945, and especially rapidly since 1964. Additional strontium 90 from past explosions will continue to reach the earth for a number of years because a considerable part of the strontium 90 is held up in the stratosphere and comes down slowly.



"The deposition of strontium 90 on the earth is affected by a number of variable factors, including seasonal changes in the behavior of stratosphere current, rain, and snowfall. As a result, the rate of strontium 90 deposition fluctuates from time to time and from place to place. Like all radioactive substances strontium 90 decays with time. The strontium 90 present in the stratosphere or on the earth loses half of its radioactivity every 20 years. From the combined effects of stratospheric holdup, the decay process, and variable influences on the rate of fallout, it can be predicted that the amount of strontium 90 resulting from past atomic explosions that reaches the earth will continue to rise in an irregular way and reach a maximum in 1970-75. The average amount of strontium 90 on the earth at that time will probably be about two to three times the amount present in 1958. Thereafter, it will decline gradually over the course of many years.

"Once on the earth's surface, strontium 90 enters into the complex chain of chemical and biological processes involved in the production of food. Being chemically similar to calcium, strontium 90 follows it through the food chain. Calcium is found in the soil, from which it is absorbed by plants, and enters the bodies of animals that eat the plants. In animals and humans, calcium is required to form bones, teeth, and milk. In the United States, the greater part of our required calcium is obtained from milk and milk products, the remainder being supplied by vegetables, cereals, and fish. Along with calcium, strontium 90 is now found in varying amounts in soil, plants, milk, and in the bones and teeth of animals and humans.

"The U.S. Public Health Service has been measuring the amount of strontium 90 in milk in the St. Louis area at monthly intervals since April 1957. Strontium 90 content is measured in relation to the amount of calcium. A strontium 90 unit is 1-millionth of a millionth of a currie of strontium 90 per gram of calcium. In April 1957, St. Louis milk contained 6.5 strontium 90 units. The last reported analysis—for September 1958—showed 15.4 units. This increase is expected from the factors already described and is expected to continue for the next 10 to 15 years, after which the amount will decline if no further explosions occur. Milk is not unusual in this respect. All foods that have been studied show similar amounts of strontium 90 relative to their calcium contents. The strontium 90 content of milk has been studied most thoroughly because it is the most important dietary source of calcium, and is therefore also the largest dietary source of strontium 90.

"All radioactive materials are hazardous and in sufficient amounts may cause harmful medical effects. The expected hazard from strontium 90 is not known precisely, because the substance is so new that medical experience with it is lacking. However, a rough estimate of the hazard can be made by comparison with the better known effects of radium, which also concentrates radioactivity in the bone. The International Committee on Radiological Protection has established such an estimate, which is called the maximum permissible concentration. This is the amount of strontium 90 which, if held in the body for a lifetime, can probably be tolerated without expectation of detectable medical damage. At present, the maximum permissible concentration for the general population is set at 80 strontium 90 units. This means that an individual can acquire one maximum permissible concentration of strontium 90 only by using during the entire period of bone growth (about 15 years) a dietary source of calcium which contains enough strontium 90 to deposit 80 strontium 90 units in the bone. What matters is not the strontium 90 content of the food at any one time, but the average level over the whole 15-year period. It is not yet known exactly what portion of the dietary strontium 90 is taken up by the body it may be as little as one-half or as much as all of the strontium 90 found in the food.

"Every person who exceeds the maximum permissible concentration will not automatically become sick. If on the average a large group of people exceed the maximum permissible concentration for strontium 90, we may expect detectable evidence of disease in a noticeable proportion of the population.

"St. Louis milk showed a yearly average for the period August 1957-August 1958 of 10.7 strontium 90 units. This represents about one-eighth of the number of strontium 90 units (80) that is presently designated as the maximum permissible concentration. To estimate the ultimate effect of milk strontium 90 on the amount of strontium 90 that the body will accumulate, we need to recall that (1) the strontium 90 level of milk is expected to rise twofold to threefold in the next 10 to 15 years, (2) not all of the food strontium 90 will remain in the

body, and (3) many of the factors that affect our estimate of the strontium 90 hazard are very poorly understood. These factors include:

"(a) The exact rate at which the strontium 90 held in the stratosphere comes down to earth is not accurately known.

"(b) There are considerable variations in the amount of strontium 90 deposited in different geographical areas; many of the reasons for these variations are not known as yet.

"(c) The exact process whereby strontium 90 enters plants has not yet been worked out; the relative amount of strontium 90 that enters by way of the roots or from rainfall on leaves affects the total strontium 90 taken up by the plant.

"(d) Various agricultural practices may influence the proportion of strontium 90 in feed that ends up in a cow's milk. Cows tend to reject a portion of the dietary strontium 90, but the factors that influence this process are not understood.

"(e) It is not yet known whether there is a threshold level of radiation which can be absorbed by the body with absolutely no expectation of harm. If a threshold exists, very low levels of radiation might be altogether harmless. If there is no threshold, any amount of radiation, however slight, increases the chance of medical harm.

"(f) The exact proportion of strontium 90 in food which ends up in the teeth and bones is not known, nor is it understood how it may vary with changes in diet and bodily activity.

"(g) The maximum permissible concentration is only a rough estimate of how much strontium 90 may be harmful. During the past 10 years, as knowledge of the harmful effects of radiation has advanced, the maximum permissible concentration has been successively reduced on three occasions, so that it now stands at a level which is one-sixteenth of that accepted 10 years ago. There is evidence that the present maximum permissible concentration may have to be reduced further; this would have the effect of increasing our expectation of harm from a given amount of strontium 90.

"In the face of these uncertainties about the strontium 90 problem, we cannot now predict whether or not this situation will be completely free of future harm. So little is known about the problem that any of the above estimates may be 5 to 10 times too high or too low. If all the unknown factors work out favorably, the strontium 90 content of milk will be of negligible significance. If most of these factors work out unfavorably the ultimate level of strontium 90 might reach the maximum permissible concentration, and some medical harm might result from the strontium 90 absorbed by children now growing up. It may take years before we know what danger exists.

"Being an essential food for all children, milk must not be eliminated from the diet. Despite present uncertainties regarding the possible effect of strontium 90 on future health, normal milk intake should not be reduced. A decrease in milk consumption would probably have no effect on strontium 90 absorption, but might adversely affect health.

"In view of these observations, prudence requires that research be undertaken to increase our knowledge of the strontium 90 hazard and to find ways for reducing the strontium 90 content of milk. As soon as practicable, the results of research on lowering strontium 90 content should be applied to the milk supply."

(For release Apr. 25, 1959)

From: Greater St. Louis Citizens' Committee for Nuclear Information—Mrs. Roberts

Dr. Barry Commoner, vice president of the Greater St. Louis Citizens' Committee for Nuclear Information, today issued a committee statement regarding reported revisions in the estimates of hazards from strontium 90.

The statement issued by Dr. Commoner on behalf of the committee follows: "The Greater St. Louis Citizens' Committee for Nuclear Information has investigated recent reports regarding revisions in the estimates of the strontium 90 hazard. These reports have been interpreted to mean that the permissible strontium 90 level for the general population has been doubled.

"The committee has investigated this matter and finds that this interpretation is unwarranted. The correct conclusion to be drawn from the new revisions of the estimated hazard is that the maximum permissible level of strontium 90

for the general population is to be reduced at least to two-thirds of the former value.

"Evaluation and revision of radiation safety standards are in the hands of the International Committee on Radiological Protection. The current reports refer to a new handbook to be issued by the National Committee on Radiation Protection and Measurements, which is affiliated with the international body. These groups meet periodically to reconsider available knowledge about the effects of radioisotopes. In recent months both national and international committees have been revising their recommendations on the tolerable amounts for 240 radioactive materials, including strontium 90.

"The new national committee handbook sets forth the estimated amount of Sr<sup>90</sup> which may be absorbed by the body and carried for a lifetime without the expectation of harm when exposure to the radioisotope occurs under occupational conditions. It does not make any recommendations regarding permissible levels for the general population.

"The international committee, however, does make recommendations regarding permissible levels for the general population. The levels are lower than for the occupational groups. Revisions have been made both in the occupational standards and in the factors which are to be used to convert these standards into value applicable to the entire population. Since the general population includes especially sensitive individuals, such as children and pregnant women who, unlike atomic workers, are not under constant medical supervision, lower permissible levels are used.

"According to the revised reports, the permissible amount of strontium 90 that may be accumulated in the bodies of occupational groups has been doubled. However, at the same time the international report states that:

"In view of the uncertainties as to the dose-effect relationships for somatic effects it is suggested that for planning purposes the average concentration of such isotopes, or mixtures thereof, in air or water, applicable to the population at large, should not exceed one-thirtieth of the maximum permissible concentration value for continuous occupational exposure given in the report of committee II." (Quoted from "The Recommendations of the International Committee on Radiological Protection." Published by Pergamon Press, London, 1959.) The report was adopted by the committee on September 9, 1958.

(Somatic effects include radiation-induced cancers, which may result from the absorption of sufficient strontium 90. The report of committee II lists the maximum amounts of 240 radioisotopes, including strontium 90, which are permitted in the bodies of persons exposed under occupational conditions.)

The suggested one-thirtieth reduction recommended in the new international report replaces the previous recommendation that permissible occupational levels be reduced to one-tenth when applied to the general population. If both of the new recommendations are taken into account, the new value for the maximum permissible concentration of strontium 90 in the general population is reduced to two-thirds of the value based on the old recommendations.

Another type of calculation leads to the conclusion that the maximum concentration of strontium 90 in milk and other foods permissible for consumption by the general population ought to be reduced from the present level of 80 micromicrocuries of strontium 90 per liter to 33 micromicrocuries per liter. The new report of the national committee recommends that for occupational groups, the allowable level of strontium 90 in water—which is used as the basis for establishing permissible levels in milk—be increased from the present value of 800 micromicrocuries per liter to 1,000 micromicrocuries per liter. If this new value is reduced thirtyfold, in keeping with the recommended ratio between occupational and general population exposures given in the new international report, the new maximum permissible concentration of strontium 90 in milk for the general population ought to be 33 micromicrocuries per liter. This represents a significant reduction from the present value of 80 micromicrocuries per liter.

Recent statements that the strontium 90 level permitted in the general population has been doubled arise from apparently incomplete knowledge of the revisions which have been recommended by the international committee.

The CNI pointed out that confusion may have resulted from the use of the new occupational levels mentioned in the national report without considering the new population factor suggested in the international report.

(The following correspondence relates to an article on p. 1940:)

CONGRESS OF THE UNITED STATES,  
JOINT COMMITTEE ON ATOMIC ENERGY,  
March 5, 1959.

Mr. A. R. LUEDECKE,  
General Manager, U.S. Atomic Energy Commission,  
Washington, D.C.

DEAR MR. LUEDECKE: A copy of the March issue of Consumer Reports contains a rather full discussion of the fallout-in-milk problem, based on a study conducted for the Consumers Union. Since the publication acknowledges AEC cooperation, I'm sure you or officials of the Biology and Medicine Division are aware of the article.

I would appreciate receiving for Joint Committee use a Commission review of the subject matter, its authenticity, an evaluation of its conclusions, and any other comments you deem appropriate.

Yours truly,

JAMES T. RAMEY, *Executive Director.*

ATOMIC ENERGY COMMISSION,  
Washington D.C., April 1, 1959.

Mr. JAMES T. RAMEY,  
Executive Director, Joint Committee on Atomic Energy,  
Congress of the United States.

DEAR MR. RAMEY: In reply to your request of March 5, 1959, our Division of Biology and Medicine has reviewed the discussion of the fallout in milk contained in the March issue of Consumer Reports and has provided the following comments.

The report on strontium 90 in milk by Consumer's Union is very well done, considering the difficulties faced by such an organization in evaluating technical problems outside its past areas of activity. It represents, we believe, a valuable contribution to public discussion of the subject.

Our most important disagreement with the statements made by Consumer's Union is in connection with the discussion of the meaning and basis of "maximum permissible limits." We do not consider, as stated in the fourth paragraph of page 104, that "any 'permissible' level obviously is predicated on the assumption that there is a threshold dose for strontium 90 below which any effects are insignificant." It is our understanding that, while individual members of the National Committee on Radiation Protection and Measurement and the International Commission on Radiological Protection may either consider it likely or unlikely that thresholds do exist, recommendations of maximum permissible levels are made on the cautious assumption that there are no thresholds for at least some of the biological effects of strontium 90. Rather, the "maximum permissible body content" is a level at which the risk of a serious biological effect to any individual is not necessarily zero, but is considered to be too small to be of serious concern. This means that we cannot say with confidence that no person in a large population will suffer a serious effect from strontium 90 at or below recommended maximum permissible levels, but, rather, that ill effects in a population from such levels are sufficiently small to be acceptable if there are reasons to accept any risk from the activities from which these risks result.

It appears probable that, if thresholds for somatic effects of strontium 90 in the body were established, these thresholds would be much higher than currently recommended limits for exposures of the general population; and that, if we had sufficient information to permit radiobiologists to agree with confidence that such thresholds exist, high "permissible limits" might be appropriate.

We do not agree in detail with a number of statements made in the report. However, some of these lie within the range of current opinion on the subjects discussed, while others involve relatively unimportant inaccuracies. Of particular interest in the analogy to bacterial contamination which we consider to be very misleading. Because the relative freedom of milk from contamination is dependent upon day-to-day control of conditions of production, it is extremely important that these be checked with each producer of milk. Concentrations of strontium 90 in milk are, however, largely independent of any measures taken

by the producer and are not subject to such large variations in time and place as to require the surveillance given bacterial contamination.

The report gives no indication of exercise of quality control on the laboratory doing the analyses. While the results reported by the Consumer's Union differ somewhat from results found by the U.S. Public Health Service in the same areas, the differences are probably no larger than is to be expected from differences in sampling techniques and possible errors in analysis.

I trust that this is the information which you desired. If you have questions on any specific part of the report, we will be glad to reply to them.

Sincerely yours,

A. R. LUEDECKE, *General Manager.*

CONGRESS OF THE UNITED STATES,  
JOINT COMMITTEE ON ATOMIC ENERGY,  
March 5, 1959.

Dr. LEROY BURNET,  
*Surgeon General, Public Health Service,  
Department of Health, Education, and Welfare,  
Washington, D.C.*

DEAR DR. BURNET: A copy of the March issue of Consumer Reports contains a rather full discussion of the fallout-in-milk problem, based on a study conducted for the Consumers Union. Since the publication acknowledges Public Health Service cooperation in the study, I'm sure you or officials of the PHS are aware of the article.

In view of the growing interest in this general subject and the announced intention of the Joint Committee's Subcommittee on Radiation to hold hearings later this year on fallout, I would appreciate your review of the subject article with appropriate comments on its authenticity, conclusions, and findings.

Sincerely yours,

JAMES T. RAMEY, *Executive Director.*

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE,  
PUBLIC HEALTH SERVICE,  
Washington, D.C., March 17, 1959.

Mr. JAMES T. RAMEY,  
*Executive Director, Joint Committee on Atomic Energy,  
Congress of the United States, Washington, D.C.*

DEAR MR. RAMEY: I appreciate your request of March 5, 1959, for our comments on the March issue of Consumer Reports related to fallout in milk, since the publication mentions the Public Health Service.

Some months ago, when the Consumers Union indicated their interest in this matter, at their request we made our data available to them, and concurrently pointed out some of the difficulties inherent in a study of this type, particularly in view of their plans to limit the study to one sample at each location. However, recognizing these difficulties, they went ahead with the study. Prior to the publication of their report, they asked for our comments, but, in view of the nature of the article, our technical personnel thought it would be in the best interests of all concerned to limit our comments to those areas particularly related to the Public Health Service data. I am attaching a copy of our letter which was written at that time to the editors of Consumer Reports.

We recognize that this article has many health and economic implications of possible concern in national policy formulation. In the short time available to us for its review, we could only check the data related specifically to our activities in this area. This was substantially correct. The scientific development of permissible radiation burden, the special hazard of strontium 90, and the uncertainties involved in definitive conclusions reflect the factors generally brought to our attention by our scientific advisers. Some of the weaknesses in our present program, such as lack of coverage, are well recognized by both our advisers and our staff personnel. The generally unsatisfactory nature of the present standards, in view of the national need to consider continuing the weapons testing program, has a high priority in our thinking.

It would appear to be improper to discuss the relative roles of the Atomic Energy Commission and the Public Health Service as expressed in this document in view of the fact that Mr. Hollifield suggested at the recent hearing on radioactive waste disposal that we should discuss this matter within the administration, and steps have been taken to work with the Atomic Energy Commission, both directly and through the Bureau of the Budget, to consider a more effective system of health protection for our Nation. At the technical level we are continuing to provide the Atomic Energy Commission with all of the data we collect which is related to this and associated problems as rapidly as it becomes available. Concurrently, they are supplying some of the funds that make certain of our activities possible and are including our data on milk and other environmental factors in some of their reports.

Sincerely yours,

JOHN D. PORTERFIELD,  
*Acting Surgeon General.*

JANUARY 20, 1959.

Mr. IRVING MICHELSON,  
*Assistant Technical Director, Consumers Union,  
Mount Vernon, N.Y.*

DEAR MR. MICHELSON: Your letter of January 9 transmitting your draft report on strontium 90 in milk is appreciated.

We have read this report with a great deal of interest and appreciate its broad scope and interest in the biological as well as the physical variables involved in this important matter and its integration into the total radiation exposure and total nutritional concept. We have not had an opportunity to check all of the individual numbers and calculations on account of time limitations. We have found but one discrepancy in the figures related to the Public Health Service data. The Public Health Service and Lamont Laboratory figures may be reversed since our average for the period was 6.0  $\mu\text{mc/l}$ .

The units used above bring up a point that we would like you to reconsider: that is the use of the strontium unit as the basis of your presentation. While it is our opinion that the strontium unit offers many advantages in dealing with the question of strontium 90 in milk, it concurrently can create many additional calculation and laboratory problems when an effort is made to integrate milk and other nutritional data with radioactivity in water and air. It will be necessary to record variable levels for strontium intake in terms of strontium units not only on the basis of the variation in the strontium per se but also on the basis of variations in the calcium content of the material. If we had sufficient data on all elements of the diet, it might be possible to suggest the most appropriate units. This data is not available at this time. Therefore, we have chosen to utilize the units recommended by the National Committee on Radiation Protection and Measurements: namely,  $\mu\text{mc/l}$ . It can easily be shown that the use of the strontium unit when applied to water supplies with low calcium content could create fear in the minds of large segments of the public. For this reason, we would appreciate it if you would record the Public Health Service data in terms of micromicrocuries per liter as well as strontium units. As a corollary to this, all interested groups would be able to evaluate your data in the context of existing NCRP standards. I am enclosing a copy of our milk data for your use if you wish to bring this portion of the report up to date.

Since your report was written we have extended our testing bases to a total of 10 cities. We concur that it is highly desirable from a public health standpoint that means be found to increase the breadth and depth of the sampling process, and our basic program is directed to assisting the States to undertake as much of this analytical work as possible.

Sincerely yours,

FRANCIS J. WEBER, M.D.,  
*Chief, Division of Radiological Health.*

[Reprinted from Student Life, Washington University, St. Louis, Dec. 19, 1958]

## THE HAZARD OF FALLOUT—NUCLEAR BOMB TEST POLICY SHOULD BE DECIDED BY ALL

(Barry Commoner, Professor of Botany, Washington University)

Certain Government policies call for the occasional explosion of nuclear weapons for experimental purposes, and their contemplated use in war. All citizens need to decide whether or not they approve of these policies. This requires that we weigh the benefits derived from present nuclear policies against their hazards. The military and political needs that our nuclear policies are supposed to answer are under constant discussion.

My purpose in this article is to present the facts required to estimate the biological hazard that results from the present policy of conducting experimental nuclear explosions. I write with the conviction that this decision should not remain in the hands of Government officials, or of scientists—but that the judgment rightfully belongs to every person that inhabits the earth.

### THREE POWERS

Three nations—the United States, the Soviet Union, and Great Britain—have been exploding nuclear weapons. Three bombs were exploded by the United States in 1945—one in a New Mexico test and two over Japanese cities—and since then, hundreds more have followed. Except for the two weapons used in Japan, all were exploded with no intention to harm anyone.

Certainly in all American tests great precautions have been taken to see that no one would be hurt. The only people hurt as an immediate consequence of these tests—such as the Japanese fishermen and the Marshall Islanders who were near one of our Pacific tests—were caught in unexpected local fallout resulting from a shift in wind direction.

The question that now agitates people all over the world is how much unintentional, and possibly unanticipated harm, will result from radioactive fallout that these explosives have spread to every part of the globe.

### RADIATION PRODUCED

Every nuclear explosion produces large amounts of radioactive materials. In atomic fission bombs some of the fragments produced when the atoms are split are radioactive elements, the most important being strontium 90. It is important because it represents the most serious health hazard in fission-produced fallout. Another radioactive element, carbon 14, is produced less directly.

The radiation given off by a nuclear explosion includes neutrons, which collide with ordinary atoms of nitrogen in the air and converts them into carbon 14. Because of its very long radioactive life—more than 10,000 years, and its importance in all forms of life, carbon 14 is also an important part of the nuclear health problem. At the moment we know much more about strontium 90 than we do about other forms of fallout radioactivity and in what follows I shall deal mainly with this element.

To judge the health hazard resulting from the 200-odd nuclear explosions we need to know how much radioactivity is produced, where it goes, how much reaches humans, and how much harm will result from human absorption of this amount of radiation. In the past few years detailed scientific studies of these problems have become available, although our areas of ignorance still greatly exceed what is known about fallout.

### BAND OF FALLOUT

The mushroom cloud formed in a nuclear explosion pushes the radioactive material high above the earth into the stratosphere. Until a few years ago it was believed that once in the stratosphere the radioactive cloud was spread evenly around the globe. Now we know that this is not true. Instead, no matter where the explosion takes place, most of the radioactivity comes to lie in a band which circles the globe in the Temperate Zone at about 30-60 degrees north latitude.

The major cities of the world lie under this band; New York, London, Berlin, Moscow, Peking, Tokyo and also St. Louis. The part of the globe which lies under this concentrated band of radioactivity includes 80 percent of the people that live on the earth.

From here it comes down very slowly; it takes about 10 years after the bomb explodes for all of it to reach the earth. It descends by mixing with moisture in clouds, finally coming to earth dissolved in rain or snow. Regions with heavy rain or snowfall tend to get more fallout radioactivity.

### CONTINUING EFFECTS

Like all radioactive elements, strontium 90 gradually loses its radioactivity, taking about 30 years to lose half of what it started with. This means that for perhaps 10 or 15 years after a nuclear explosion the strontium 90 which it produces will continue to come down to the earth and will for some dozens of years continue to give off radioactivity.

To find out how much strontium 90 is reaching the earth from fallout, the Atomic Energy Commission and other laboratories have set up collection stations in various parts of the world. For example rain and snow collected in New York City showed no strontium 90 before atomic explosions began but then rose steadily; the most recent available measurements made in May 1958 shows about 40 millicuries of strontium 90 radioactivity per square mile. Even if no more tests take place, strontium 90 will continue to fall on the earth for 10 to 15 years.

What happens when strontium 90 is deposited on the earth depends on its chemical similarity to calcium, a substance which is found in the soil and which is used by animals and plants. Calcium is absorbed from the soil by plants, and animals obtain the calcium that they need by feeding on the plants. Animals require calcium mainly for the growth of bones and teeth; in cows much of the calcium appears in the milk. Human beings obtain their required calcium largely by drinking milk, but also from vegetables, cereals, or fish.

### SIMILAR TO CALCIUM

Wherever calcium occurs we find strontium 90 as well. Being chemically similar to calcium, strontium 90 follows calcium from the soil into plants, into animals and through milk and other foods into human beings.

As the soil accumulates an increasing burden of strontium 90, the amount in plants goes up and with it the amount that we find in the milk of cows that feed on these plants. Because milk is such an important food its strontium 90 content has been studied in a number of places in the United States and elsewhere.

In some places such as New York the strontium 90 content of milk has been rising gradually and during the summer of 1958 reached four to five microcuries of strontium 90 per liter. In other parts of the country, the strontium content of milk has gone up considerably faster and fluctuates more widely.

### ST. LOUIS SECOND

Of the 10 or so areas of the United States that have been studied 2 stand out as exhibiting the most rapid increase in milk strontium 90. One of these is at Mandan, N. Dak., where milk reached a value of 29 microcuries of strontium 90 per liter last summer. The second highest reports of milk strontium 90 come from St. Louis where in November 1958 milk contained 20.1 microcuries of strontium 90 per liter. No one really knows why the strontium 90 content of milk varies so much from month to month and from place to place.

How much strontium 90 are humans absorbing from food? Unfortunately, very little is known about the actual amount of strontium 90 that human beings have taken up. Only a few hundred samples of human bone have been analyzed for strontium 90 thus far and these come from scattered areas all over the world.

In the absence of detailed information one can make some theoretical estimates based on our much more extensive information on the amount of strontium 90 in the diet and our knowledge of how calcium—and strontium 90—pass from the diet into human bones and teeth.



## MAINLY WITH CHILDREN

The uptake of strontium 90 by bones and teeth occurs chiefly when they are growing so that the problem mainly has to do with children. The ratio of the strontium 90 content of food to the resultant concentration in the bones is not well known. On the whole the strontium 90 content of bones will be not less than half, but may be the same as the concentration of strontium 90 that exists in the diet which a child eats during the time when the bone is being formed. For example, a child raised on milk averaging 10 strontium units would be expected at maturity to have in its bones about 5 to 10 units of strontium 90.

Estimates of this kind are very rough and do not take into account the great variability among different individuals. How great individual variations in strontium 90 uptake can be is clear from even the few available measurements of the amount of strontium 90 in the bones of different humans.

The most complete study of the amounts of strontium 90 in children's bones available thus far shows that of every 1,000 children 4 will contain in their bones 10 times the average amount of strontium 90. When one deals with the entire population of the earth, even such a small proportion becomes a rather large number.

## HOW HARMFUL?

How harmful is the strontium 90 that comes to rest in the bones and teeth? There is no simple answer to this question. Since strontium 90 is so new we do not yet have any direct medical experience with its effects. Damage to humans might take 30 to 40 years to show up. At that time, if a wide public health survey were done on the health of the people who comprise the present generation of children, we would find out what the damage has been.

In the absence of this information an estimate of the hazard can be made by comparing the amount of strontium 90 radioactivity expected to accumulate in bones with previous medical experience on the effects of other radioactive materials.

## MEDICALLY LIKE RADIUM

Medically the material most closely resembling strontium 90 is radium. Like strontium 90, radium is radioactive, seeks out the bone, and remains there through the lifetime. Unfortunately, there are people who have eaten significant amounts of radium. Most well known are the case histories of about 100 women, who in the 1920's worked as dial painters in a New Jersey radium watch dial factory.

These women made tips on the paint brushes with their lips, and in that way absorbed varying, but largely lethal, amounts of radium. Their cases have been followed, and the medical damage which they suffered—bone diseases and various types of cancer—have been compared with measurements of the amounts of radium radioactivity found in their bodies.

From this experience it is possible to make a rough estimate of the amounts of strontium 90 radiation that might be tolerated in a human's bones without expectation of medical damage. This estimated tolerance level has been established by an international group of radiologists (the International Commission for Radiological Protection) and it leads to a number called the maximum permissible concentration (MPC).

## MPC

For strontium 90 the MPC is that concentration of strontium 90 in the diet, or in the body, beyond which one must not go without incurring the risk of observable medical damage. In other words, it is the upper limit which cannot be exceeded in safety.

This does not mean that every person who exceeds the MPC will automatically become sick. It means that if on the average a large group of people exceed the MPC for strontium 90 we may expect in a noticeable proportion of the population—the younger and more sensitive individuals—detectable evidence of disease. The uncertainties involved in establishing the MPC level are so great that it may easily be five times too high, or five times too low.

How does the strontium content of the present diet compare with the tolerable level established by the MPC? In St. Louis the highest strontium 90 level reached up to December 1958 was 20.1 units (for November 1958), and the average during the period August 1957 to August 1958 was about 10 units.

## EIGHTY UNITS MAXIMUM

The MPC for strontium 90 established by the expert committee is 80 units. This means that in November 1958 milk in the St. Louis area reached about one-fourth of the maximum permissible strontium 90 concentration. Even if no more tests occur, the strontium 90 that will continue to drop out of the stratosphere for the next 10 years will increase the present level two to threefold.

A child growing to maturity during the next 10 to 15 years in St. Louis may be expected to drink milk containing an overall average of about 35 to 50 percent of the MPC—if there are no more nuclear explosions. At maturity the child's bones would be expected to have a strontium 90 content amounting to 25 to 50 percent of the MPC.

There are great uncertainties attached to all of these figures. If all, or most, of the uncertainties work out in our favor it will turn out that children now growing up in this area will at maturity contain in their bones only a small fraction of the maximum permissible concentration of strontium 90. If the most of the unknowns turn out in the pessimistic direction, the average child may reach maturity carrying a permanent deposit of bone strontium 90 that exceeds the maximum permissible concentration, and that can eventually lead to medical harm.

## WORLDWIDE EFFECTS

In the past few years several skillful groups of scientists have worked hard to estimate the effects of fallout on the entire world population. A U.N. committee of international experts—which included several AEC scientists—made a 2-year study of the question and published a report in July 1958.

About a year ago the Biology and Medicine Advisory Committee of the AEC reported on it. Earlier a group of about 50 scientists testified on this matter before lengthy hearings of the Joint Congressional Committee on Atomic Energy. These groups considered what effect fallout may have on the incidence of cancer, and on harmful changes in inheritance.

Significantly, all of these groups reached about the same conclusions: Fallout from the nuclear explosions completed up to 1957 may be expected to cause in the world population something like a 0.2 to 2-percent increase in the number of serious genetic effects and a similar increase in the incidence of cancer. If one of the present unknown factors—the possibility that at extremely low intensities radiation will not influence the cancer forming process—turns out in our favor, there may be no detectable increase in cancer. At the moment, this is a rather unlikely outcome.

## POLITICAL OUTLOOK

Having reached this point in our efforts to evaluate the hazard from fallout radioactivity, we come to the end of the purely scientific matters. The conclusion just described is scientific, but any further interpretation placed upon it depends a great deal on what moral or political outlook we wish to support.

For example, if a 0.2 to 2 percent fallout-induced increase in the natural incidence of leukemia is applied to a city where 100 cases of this disease occur per year, the annual effect of fallout may be less than 1 additional case. The effect of fallout then appears to be negligible. On the other hand, if we are concerned with the effects beyond our own city and calculate the expected number of fallout-induced cases on a worldwide basis, the effect is not a small one.

The number of cases of leukemia and bone cancer expected from fallout of bombs exploded up to 1957 is between 25,000 and 100,000 per generation of the world population. The same calculation leads to the expectation of between 2,500 and 13,000 cases of serious birth defects in the next world generation as a result of this fallout.

## "TRIVIAL"—TELLER

Dr. Edward Teller and a few other scientists contend that the effect of fallout on health is trivial. To support this conclusion Dr. Teller shows that the fallout from one large bomb will subtract from the life of the average American only three one-hundredths of a day, or about three-quarters of an hour. Most people would probably feel that three-quarters of an hour out of their life is an acceptably small price to pay for whatever national safety is derived from this kind of a test.

However, a more internationally minded person will remember that the payment is made not only by Americans but by everyone living on the earth. The

total cost of fallout damage from one bomb to the entire human race is 300,000 man-years. This is equivalent to 1 year off the life of 300,000 people. It is also equivalent to killing 10,000 people at the age of 40. The same calculations show that tests concluded up to 1957 will cost in human life more than the battle deaths in World War I.

In this light, Dr. Teller's statistic is a matter not to be lightly dismissed. This shows how easily the same numbers can be rearranged to make a numerical conclusion that will give some degree of comfort to quite opposing judgments.

#### BEGGING THE QUESTION

Some perspective can be gained from comparisons with other hazards. For those who smoke, the medical hazard due to fallout is probably less than the increased incidence of disease that results from smoking cigarettes. But this begs the question, for no one has yet proposed that we should expose everyone on the earth, now and for some generations to come, to the hazard incurred by those who now choose to smoke.

It is also helpful to look for possible trends in the recent history of the scientific evolution of the fallout hazard. Do our expectations become more optimistic with time or does new knowledge add to our pessimism regarding the expected medical effects of fallout?

In 1956 Commissioner Libby of the AEC published a detailed paper (Proc. Nat. Acad. of Sciences, June 1956) in which he predicted the future course of the strontium 90 problem. He predicted that fallout from the tests carried out to that date would reach a maximum in 1970 after which the radioactivity would decline slowly due to the decay of strontium 90. He predicted that for the United States the 1970 maximum would be 7 millicuries of strontium 90 per square mile. But in May 1958, AEC analysis of strontium 90 fallout over New York City gave a figure of 43 millicuries of strontium 90 per square mile and by 1970 it will be considerably higher.

#### PREDICTIONS WRONG

Libby predicted that in 1970 milk in the United States would reach a maximum level of about 8.4 strontium 90 units. Recall that in November 1958 St. Louis milk had already reached the level of 20.1 strontium units, and milk at Mandan, N. Dak., was even higher. And, according to Dr. Libby's estimates, milk radioactivity will increase twofold or threefold between 1958 and 1970.

Thus predictions made only 2 years ago turn out now to be overoptimistic. This trend has been a general one as the following examples show:

*The distribution of fallout over the earth.*—In 1953, the assumption was made in AEC publications that fallout would be evenly distributed over the globe so that no restricted area would receive an excessive amount. In 1950-57 a controversy developed over this matter. The AEC view was challenged by a U.S. Weather Bureau expert who claimed that fallout would concentrate in the North Temperate Zone, and so expose the great bulk of the world population to a level of radioactivity several times higher than the level predicted by the theory of even distribution. In 1958 the actual measurements of fallout distribution showed that the AEC's original idea was wrong, and that a considerable concentration of fallout existed in the 30° to 60° north latitudes.

*The proper choice of maximum permissible concentration.*—In all AEC statements up to January 1957, the hazard of fallout was judged against the maximum permissible concentration (MPC) established for use with respect to workers in atomic plants. Since these workers are under constant medical supervision and can be removed from contact with radioactivity if they develop any signs of damage, the International Commission allows an MPC which is 10 times more liberal than the MPC allowed for ordinary populations.

In 1956-57, controversy arose on this point, with the AEC continuing to use the more liberal occupational MPC even where populations were concerned while other scientists preferred to use the more conservative MPC. In January 1957, the AEC abandoned the use of liberal MPC for populations and applied the 10 times more conservative value that had been urged by independent scientists.

*Dietary factors affecting strontium 90 absorption.*—In the 13th Semiannual Report of the AEC, published in 1953, the AEC stated that the only possible hazard to humans from strontium 90 would arise from "The ingestion of bone splinters which might be intermingled with muscle tissue during butchering and cutting of the meat." No mention of milk was made.

By 1956 the AEC acknowledged that strontium 90 was present in milk and that this source represented the most serious aspect of the strontium 90 hazard. Current reports from AEC and other laboratories show that additional significant amounts of strontium 90 are also being absorbed from vegetables and cereals.

*What dangerous isotopes are there in fallout?*—Until very recently there was universal agreement that the radioactive hazard from fallout was due only to strontium 90. Last spring, Prof. Linus Pauling of the California Institute of Technology reported, on the basis of calculations derived from new data published by Libby, that in the long run carbon 14, a radioactive element produced in especially large amounts in the explosions of so-called clean bombs, represented a more serious hazard than strontium 90. Pauling was criticized by several scientists working on AEC projects. However, just a few weeks ago, an official AEC scientific report on this matter fully confirmed Pauling's conclusions.

*The genetic hazard from fallout.*—In 1953, the 13th Semiannual Report of the AEC stated that "Fallout radioactivity is far below the level which could cause a detectable increase in mutations, or inheritable variations." This optimistic conclusion was challenged by a number of geneticists. In 1957 the report of the AEC Biological and Medical Advisory Committee concluded that fallout from tests completed to that date would result in 2,500 to 13,000 cases of serious genetic defects per year.

I have recited a series of facts which show that in the recent past the estimate of the medical hazard from fallout has been consistently underrated. As we learn more about fallout, the probable hazardous results of its radioactivity appear to be more and more severe.

These changes have not come about by themselves. A good part of the reexamination of the fallout problem has come about because beginning in 1955 the facts about fallout became available to scientists generally. Before 1953 there were no papers published in the scientific journals on the fallout problem, although Government agencies had been at work in the field for some years.

In 1955 the National Academy of Sciences began to investigate the problem and in 1956 the Academy published a report which emphasized the importance of protecting the public against various forms of radioactivity. From then on an increasing flow of information about the fallout situation began to appear in the scientific journals and in separately published reports.

#### DISCUSSION CORRECTIVE

Most of the reevaluation of the fallout hazard that I have just described has come about as a natural result of open scientific discussion of the facts.

This discussion of the fallout hazard has also brought the issue before the public. Until a few years ago, the public had no way of knowing that the little information about fallout then allowed to reach the public press was uncertain, incomplete, or sometimes in error. Discussion among scientists served to bring the whole problem out into the open.

Since scientists were the first group to become familiar with the facts about fallout, it was natural that they initiated the debate on the Nation's nuclear policies. But it is fortunate that the issue has now reached the public generally. There is no scientific basis for judging the relative worth of the political gains which result from nuclear tests—and the human lives which they cost.

#### ETHICAL JUDGMENT

This is a question which is decided by an ethical judgment derived from political aims, religious conviction, or humanistic ideals. No scientist can claim a superior competence to make the proper judgment. My own conclusion that nuclear tests should be stopped by international agreement, and nuclear war forbidden, is no more or less significant than the judgment reached by any other informed person.

The most important aspect of the nuclear hazard has not yet even reached the pages of the journals of science. This is the problem of the biological hazards that may result from a full-scale nuclear war. There are practically no data available to scientists concerning what might happen to life in the event that a nuclear war produced a level of fallout thousands of times greater than any anticipated from our present more or less peaceful use of nuclear weapons.

## REALISTIC LOOK AT WAR

The recent overoptimism about fallout from testing suggests that the present estimates of the casualties expected from a nuclear war, enormous as they are, may also be overly optimistic. It is important that this information get into the hands of the scientific community so that it can be discussed, made more accurate, and modified to the point where it can provide all of us with a realistic picture of what a nuclear war would truly mean.

When this is done, it may turn out that a large-scale war would kill all living things on the earth. It seems to me that every human being should know whether a declaration of nuclear war is a decision for mass suicide. When everyone fully appreciates the destructive power of modern science, there is some hope that social morality will see to it that science is used only for those creative purposes which are its true goal.

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE,  
PUBLIC HEALTH SERVICE,  
Washington, D.C., October 3, 1959.

The Public Health Service reported today on the levels of radioactivity in milk collected during July from 11 sampling stations across the country. (See also pp. 197, 211, and 227.)

Both the monthly levels and the longer-term averages for all radioactive isotopes analyzed in the milk samples from all stations remained below the levels which the National Committee on Radiation Protection and Measurements considers permissible for life-time exposure by the general population.

The levels of radioactivity continued to fluctuate. The strontium 90 count decreased in July at all but 2 of the 11 stations. The Fargo, N. Dak.-Moorhead, Minn., area station showed a strontium 90 content of 22.1 micromicrocuries per liter, as compared with 20.6 micromicrocuries per liter in June. In the St. Louis area the strontium count was 17.6 micromicrocuries as compared with 11.2 micromicrocuries per liter in June and 34.8 micromicrocuries in May.

The maximum permissible concentration of strontium 90 recommended by the National Committee on Radiation Protection and Measurements for lifetime exposure of the general population is 80 micromicrocuries per liter.

The milk sampling network is part of the Service's program of measurement of radioactivity in air, water, and food. Milk was chosen for study of specific isotopes in foods because it is the most practical sample and is produced throughout the year in all sections of the country.

NOTE TO CORRESPONDENTS.—The complete data for July, together with average levels for each of the 11 stations, are shown on the attached tables. July data were not available from a recently-established station at St. George, Utah, where the average level of strontium 90 through June was 6.3.

## U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, PUBLIC HEALTH SERVICE

TABLE 1.—Analysis summary of samples collected in July 1959 from milksheds serving specified areas

(Micromicrocuries per liter)

| Area                                                                | Iodine<br>131    | Stron-<br>tium 89 | Stron-<br>tium 90 | Barium<br>140    | Cesium<br>137    |
|---------------------------------------------------------------------|------------------|-------------------|-------------------|------------------|------------------|
| Permissible limits, <sup>1</sup> lifetime average exposure (NCRP&M) | 13,000           | 17,000            | 80.0              | 200,000          | 150,000          |
| Atlanta, Ga.                                                        | 0                | 19                | 15.9              | 0                | 109              |
| Austin, Tex.                                                        | 0                | 7                 | 6.3               | 0                | 68               |
| Chicago, Ill.                                                       | 0                | 10                | 11.7              | 0                | 82               |
| Cincinnati, Ohio                                                    | 0                | 16                | 10.6              | 0                | 82               |
| Fargo, N. Dak.-Moorhead, Minn.                                      | 0                | 31                | 22.1              | 0                | 90               |
| New York, N.Y.                                                      | 12               | 9                 | 14.6              | 0                | 81               |
| Overton, Nev.                                                       | 0                | 2                 | 1.5               | 0                | 87               |
| Sacramento, Calif.                                                  | 0                | 5                 | 4.3               | 0                | 68               |
| Salt Lake City, Utah                                                | 0                | 16                | 9.4               | 0                | 61               |
| Spokane, Wash.                                                      | 0                | 24                | 18.3              | 0                | 78               |
| St. George, Utah                                                    | ( <sup>2</sup> ) | ( <sup>2</sup> )  | ( <sup>2</sup> )  | ( <sup>2</sup> ) | ( <sup>2</sup> ) |
| St. Louis, Mo.                                                      | 0                | 27                | 17.6              | 0                | 111              |

<sup>1</sup> These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being applicable to milk.

<sup>2</sup> July data not available.

TABLE 2.—Milk samples—Average levels for period ending July 1959

(Micromicrocuries per liter)

| Area                                                                | Number<br>of months<br>in re-<br>porting<br>period | Iodine<br>131    | Strontium<br>89  | Strontium<br>90  | Barium<br>140    | Cesium<br>137    |
|---------------------------------------------------------------------|----------------------------------------------------|------------------|------------------|------------------|------------------|------------------|
| Permissible limits, <sup>1</sup> lifetime average exposure (NCRP&M) |                                                    | 13,000           | 17,000           | 80.0             | 200,000          | 150,000          |
| Atlanta, Ga.                                                        | 12                                                 | 15               | 69               | 14.1             | 7                | 62               |
| Austin, Tex.                                                        | 12                                                 | 27               | 38               | 5.6              | 6                | 53               |
| Chicago, Ill.                                                       | 12                                                 | 14               | 34               | 8.4              | 3                | 69               |
| Cincinnati, Ohio                                                    | 12                                                 | 23               | 50               | 12.5             | 16               | 63               |
| Fargo, N. Dak.-Moorhead, Minn.                                      | 12                                                 | 17               | 50               | 14.2             | 9                | 76               |
| New York, N.Y.                                                      | 12                                                 | 17               | 29               | 8.5              | 8                | 66               |
| Overton, Nev.                                                       | 5                                                  | 1                | 4                | 3.4              | 0                | 38               |
| Sacramento, Calif.                                                  | 12                                                 | 7                | 20               | 5.4              | 1                | 54               |
| Salt Lake City, Utah                                                | 12                                                 | 14               | 19               | 6.0              | 4                | 44               |
| Spokane, Wash.                                                      | 12                                                 | 19               | 37               | 12.0             | 8                | 80               |
| St. George, Utah                                                    | ( <sup>2</sup> )                                   | ( <sup>2</sup> ) | ( <sup>2</sup> ) | ( <sup>2</sup> ) | ( <sup>2</sup> ) | ( <sup>2</sup> ) |
| St. Louis, Mo.                                                      | 12                                                 | 23               | 135              | 19.9             | 20               | 93               |

<sup>1</sup> These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being applicable to milk.

<sup>2</sup> July data not available.

Results of composite samples from Atlanta, Ga., milkshed for period ending July 1959

| Date of collection | Calcium content (grams per liter) |                  | Radioactivity in micromicrocuries per liter <sup>1</sup> |                  |              |                  |              |                  |            |                  |            |                  |
|--------------------|-----------------------------------|------------------|----------------------------------------------------------|------------------|--------------|------------------|--------------|------------------|------------|------------------|------------|------------------|
|                    |                                   |                  | Iodine 131                                               |                  | Strontium 89 |                  | Strontium 90 |                  | Barium 140 |                  | Cesium 137 |                  |
|                    | Sample                            | 12-month average | Sample                                                   | 12-month average | Sample       | 12-month average | Sample       | 12-month average | Sample     | 12-month average | Sample     | 12-month average |
| 1958               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Aug. 2             | 1.188                             |                  | 65                                                       |                  | 114          |                  | 11.9         |                  | 50         |                  | 103        |                  |
| Sept. 2            | 1.154                             |                  | 20                                                       |                  | 72           |                  | 13.8         |                  | 7          |                  | 79         |                  |
| Oct. 2             | 1.220                             |                  | 6                                                        |                  | 76           |                  | 10.4         |                  | 4          |                  | 77         |                  |
| Nov. 2             | 1.193                             |                  | 32                                                       |                  | 30           |                  | 8.8          |                  | 8          |                  | 56         |                  |
| Dec. 3             | 1.214                             |                  | 21                                                       |                  | 27           |                  | 10.2         |                  | 8          |                  | 72         |                  |
| 1959               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Jan. 7             | 1.242                             |                  | 7                                                        |                  | 62           |                  | 13.4         |                  | 8          |                  | 84         |                  |
| Feb. 3             | 1.218                             |                  | 5                                                        |                  | 62           |                  | 7.3          |                  | 0          |                  | 80         |                  |
| Mar. 3             | 1.246                             |                  | 4                                                        |                  | 100          |                  | 14.0         |                  | 0          |                  | 98         |                  |
| Apr. 7             | 1.181                             |                  | 3                                                        |                  | 131          |                  | 20.8         |                  | 0          |                  | 114        |                  |
| May 5              | 1.265                             | 1.204            | 16                                                       | 16               | 94           | 70               | 22.8         | 13.1             | 0          | 9                | 143        | 95               |
| June 11            | 1.249                             | 1.211            | 15                                                       | 17               | 42           | 71               | 19.9         | 13.6             | 0          | 8                | 105        | 94               |
| July 11            | 1.113                             | 1.207            | 0                                                        | 15               | 19           | 69               | 18.9         | 14.1             | 0          | 7                | 102        | 93               |

<sup>1</sup> These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

|              | Micromicrocuries per liter |
|--------------|----------------------------|
| Iodine 131   | 3,000                      |
| Strontium 89 | 7,000                      |
| Strontium 90 | 80                         |
| Barium 140   | 200,000                    |
| Cesium 137   | 150,000                    |

Results of composite samples from Austin, Tex., milkshed for period ending July 1959

| Date of collection | Calcium content (grams per liter) |                  | Radioactivity in micromicrocuries per liter <sup>1</sup> |                  |              |                  |              |                  |            |                  |            |                  |
|--------------------|-----------------------------------|------------------|----------------------------------------------------------|------------------|--------------|------------------|--------------|------------------|------------|------------------|------------|------------------|
|                    |                                   |                  | Iodine 131                                               |                  | Strontium 89 |                  | Strontium 90 |                  | Barium 140 |                  | Cesium 137 |                  |
|                    | Sample                            | 12-month average | Sample                                                   | 12-month average | Sample       | 12-month average | Sample       | 12-month average | Sample     | 12-month average | Sample     | 12-month average |
| 1958               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Aug. 6             | 1.160                             |                  | 50                                                       |                  | 40           |                  | 3.4          |                  | 18         |                  | 51         |                  |
| Sept. 4            | 1.121                             |                  | 16                                                       |                  | 32           |                  | 3.9          |                  | 6          |                  | 48         |                  |
| Oct. 3             | 1.148                             |                  | 11                                                       |                  | 35           |                  | 5.1          |                  | 0          |                  | 33         |                  |
| Nov. 5             | 1.172                             |                  | 181                                                      |                  | 49           |                  | 3.7          |                  | 30         |                  | 42         |                  |
| Dec. 3             | 1.176                             |                  | 39                                                       |                  | 32           |                  | 2.6          |                  | 12         |                  | 44         |                  |
| 1959               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Jan. 6             | 1.216                             |                  | 6                                                        |                  | 27           |                  | 5.7          |                  | 2          |                  | 39         |                  |
| Feb. 5             | 1.152                             |                  | 10                                                       |                  | 37           |                  | 6.3          |                  | 3          |                  | 48         |                  |
| Mar. 4             | 1.169                             |                  | 2                                                        |                  | 68           |                  | 7.3          |                  | 0          |                  | 62         |                  |
| Apr. 7             | 1.158                             |                  | 0                                                        |                  | 67           |                  | 8.9          |                  | 0          |                  | 60         |                  |
| May 7              | 1.179                             | 1.159            | 11                                                       | 28               | 38           | 30               | 6.5          | 4.9              | 0          | 6                | 69         | 50               |
| June 5             | 1.123                             | 1.160            | 1                                                        | 28               | 24           | 30               | 8.2          | 5.4              | 0          | 6                | 78         | 51               |
| July 7             | 1.063                             | 1.153            | 0                                                        | 27               | 7            | 38               | 6.3          | 5.6              | 0          | 6                | 68         | 53               |

<sup>1</sup> These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

|              | Micromicrocuries per liter |
|--------------|----------------------------|
| Iodine 131   | 3,000                      |
| Strontium 89 | 7,000                      |
| Strontium 90 | 80                         |
| Barium 140   | 200,000                    |
| Cesium 137   | 150,000                    |



Results of composite samples from Chicago, Ill., milkshed for period ending July 1959

| Date of collection | Calcium content (grams per liter) |                  | Radioactivity in micromicrocuries per liter <sup>1</sup> |                  |              |                  |              |                  |            |                  |            |                  |
|--------------------|-----------------------------------|------------------|----------------------------------------------------------|------------------|--------------|------------------|--------------|------------------|------------|------------------|------------|------------------|
|                    | Sample                            | 12-month average | Iodine 131                                               |                  | Strontium 89 |                  | Strontium 90 |                  | Barium 140 |                  | Cesium 137 |                  |
|                    |                                   |                  | Sample                                                   | 12-month average | Sample       | 12-month average | Sample       | 12-month average | Sample     | 12-month average | Sample     | 12-month average |
| 1958               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Aug. 18            | 1.098                             |                  | 43                                                       |                  | 64           |                  | 9.3          |                  | 18         |                  | 88         |                  |
| Sept. 16           | 1.161                             |                  | 13                                                       |                  | 54           |                  | 7.9          |                  | 16         |                  | 71         |                  |
| Oct. 14            | 1.123                             |                  | 20                                                       |                  | 53           |                  | 6.0          |                  | 1          |                  | 55         |                  |
| Nov. 10            | 1.141                             |                  | 56                                                       |                  | 64           |                  | 8.4          |                  | 3          |                  | 64         |                  |
| Dec. 17            | 1.103                             |                  | 8                                                        |                  | 14           |                  | 7.0          |                  | 8          |                  | 71         |                  |
| 1959               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Jan. 14            | 1.131                             |                  | 4                                                        |                  | 6            |                  | 6.7          |                  | 0          |                  | 64         |                  |
| Feb. 16            | 1.119                             |                  | 8                                                        |                  | 1            |                  | 6.3          |                  | 0          |                  | 71         |                  |
| Mar. 17            | 1.085                             |                  | 5                                                        |                  | 6            |                  | 5.5          |                  | 0          |                  | 59         |                  |
| Apr. 10            | 1.143                             |                  | 3                                                        |                  | 7            |                  | 7.2          |                  | 0          |                  | 64         |                  |
| May 10             | 1.128                             |                  | 0                                                        |                  | 57           |                  | 12.5         |                  | 0          |                  | 67         |                  |
| June 17            | 1.164                             | 1.122            | 2                                                        | 24               | 19           | 37               | 12.1         | 8.0              | 0          | 6                | 76         | 72               |
| July 14            | 1.011                             | 1.117            | 0                                                        | 74               | 18           | 34               | 11.7         | 8.4              | 0          | 3                | 82         | 69               |

<sup>1</sup> These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Micromicrocuries per liter

|              |         |
|--------------|---------|
| Iodine 131   | 3,000   |
| Strontium 89 | 7,000   |
| Strontium 90 | 80      |
| Barium 140   | 200,000 |
| Cesium 137   | 150,000 |

Results of composite samples from Cincinnati, Ohio, milkshed for period ending July 1959

| Date of collection | Calcium content (grams per liter) |                  | Radioactivity in micromicrocuries per liter <sup>1</sup> |                  |              |                  |              |                  |            |                  |            |                  |
|--------------------|-----------------------------------|------------------|----------------------------------------------------------|------------------|--------------|------------------|--------------|------------------|------------|------------------|------------|------------------|
|                    | Sample                            | 12-month average | Iodine 131                                               |                  | Strontium 89 |                  | Strontium 90 |                  | Barium 140 |                  | Cesium 137 |                  |
|                    |                                   |                  | Sample                                                   | 12-month average | Sample       | 12-month average | Sample       | 12-month average | Sample     | 12-month average | Sample     | 12-month average |
| 1958               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Aug. 13.....       | 1.102                             | 1.155            | 42                                                       | 76               | 97           | 63               | 7.5          | 7.1              | 84         | 39               | 84         | 58               |
| Sept. 19.....      | 1.132                             | 1.153            | 5                                                        | 40               | 98           | 65               | 9.4          | 7.4              | 13         | 29               | 59         | 58               |
| Oct. 16.....       | 1.175                             | 1.149            | 31                                                       | 18               | 50           | 59               | 8.6          | 7.5              | 8          | 24               | 53         | 59               |
| Nov. 14.....       | 1.157                             | 1.146            | 177                                                      | 33               | 108          | 64               | 15.2         | 8.2              | 10         | 24               | 64         | 61               |
| Dec. 22.....       | 1.148                             | 1.145            | 8                                                        | 33               | 37           | 66               | 9.6          | 8.5              | 4          | 24               | 63         | 63               |
| 1959               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Jan. 15.....       | 1.141                             | 1.142            | 2                                                        | 33               | 33           | 68               | 11.7         | 9.1              | 4          | 24               | 55         | 64               |
| Feb. 26.....       | 1.155                             | 1.142            | 4                                                        | 34               | 14           | 69               | 12.2         | 9.8              | 0          | 24               | 60         | 64               |
| Mar. 16.....       | 1.150                             | 1.148            | 1                                                        | 34               | 19           | 70               | 12.9         | 10.6             | 0          | 24               | 61         | 64               |
| Apr. 15.....       | 1.173                             | 1.150            | 1                                                        | 32               | 39           | 73               | 16.5         | 11.4             | 0          | 24               | 63         | 66               |
| May 19.....        | 1.150                             | 1.149            | 4                                                        | 32               | 53           | 71               | 15.2         | 12.2             | 0          | 23               | 59         | 69               |
| June 16.....       | 1.151                             | 1.143            | 2                                                        | 32               | 32           | 65               | 17.4         | 12.7             | 0          | 20               | 56         | 67               |
| July 16.....       | 1.052                             | 1.140            | 0                                                        | 23               | 16           | 50               | 10.5         | 12.5             | 0          | 10               | 52         | 67               |

<sup>1</sup> These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Micromicrocuries per liter

|              |         |
|--------------|---------|
| Iodine 131   | 3,000   |
| Strontium 89 | 7,000   |
| Strontium 90 | 80      |
| Barium 140   | 200,000 |
| Cesium 137   | 150,000 |

Results of composite samples from Fargo, N. Dak.-Moorhead, Minn., milkshed for period ending July 1959

| Date of collection | Calcium content (grams per liter) |                  | Radioactivity in micromicrocuries per liter <sup>1</sup> |                  |              |                  |              |                  |            |                  |            |                  |
|--------------------|-----------------------------------|------------------|----------------------------------------------------------|------------------|--------------|------------------|--------------|------------------|------------|------------------|------------|------------------|
|                    |                                   |                  | Iodine 131                                               |                  | Strontium 89 |                  | Strontium 90 |                  | Barium 140 |                  | Cesium 137 |                  |
|                    | Sample                            | 12-month average | Sample                                                   | 12-month average | Sample       | 12-month average | Sample       | 12-month average | Sample     | 12-month average | Sample     | 12-month average |
| 1958               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Aug. 3             | 1.116                             |                  | 48                                                       |                  | 53           |                  | 19.2         |                  | 14         |                  | 96         |                  |
| Sept. 4            | 1.125                             |                  | 27                                                       |                  | 140          |                  | 14.1         |                  | 53         |                  | 113        |                  |
| Oct. 1             | 1.215                             |                  | 20                                                       |                  | 161          |                  | 15.0         |                  | 18         |                  | 57         |                  |
| Oct. 30            | 1.166                             |                  | 86                                                       |                  | 53           |                  | 11.5         |                  | 28         |                  | 56         |                  |
| Dec. 4             | 1.165                             |                  | 0                                                        |                  | 31           |                  | 12.3         |                  | 0          |                  | 77         |                  |
| Dec. 31            | 1.159                             |                  | 2                                                        |                  | 27           |                  | 12.3         |                  | 1          |                  | 67         |                  |
| 1959               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Feb. 4             | 1.135                             |                  | 8                                                        |                  | 17           |                  | 11.8         |                  | 0          |                  | 61         |                  |
| Mar. 9             | 1.109                             |                  | 5                                                        |                  | 12           |                  | 12.2         |                  | 0          |                  | 67         |                  |
| Apr. 7             | 1.163                             |                  | 0                                                        |                  | 10           |                  | 12.3         |                  | 0          |                  | 61         |                  |
| May 15             | 1.136                             | 1.142            | 1                                                        | 27               | 20           | 62               | 16.2         | 13.3             | 0          | 15               | 71         | 83               |
| June 12            | 1.153                             | 1.146            | 6                                                        | 24               | 44           | 59               | 20.6         | 13.7             | 0          | 13               | 90         | 81               |
| July 7             | 1.084                             | 1.144            | 0                                                        | 17               | 31           | 50               | 22.1         | 14.2             | 0          | 9                | 90         | 76               |

<sup>1</sup> These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Micromicrocuries per liter

|              |         |
|--------------|---------|
| Iodine 131   | 3,000   |
| Strontium 89 | 7,000   |
| Strontium 90 | 80      |
| Barium 140   | 200,000 |
| Cesium 137   | 150,000 |

Results of composite samples from New York, N.Y., milkshed for period ending July 1959

| Date of collection | Calcium content (grams per liter) |                  | Radioactivity in micromicrocuries per liter <sup>1</sup> |                  |              |                  |              |                  |            |                  |            |                  |
|--------------------|-----------------------------------|------------------|----------------------------------------------------------|------------------|--------------|------------------|--------------|------------------|------------|------------------|------------|------------------|
|                    |                                   |                  | Iodine 131                                               |                  | Strontium 89 |                  | Strontium 90 |                  | Barium 140 |                  | Cesium 137 |                  |
|                    | Sample                            | 12-month average | Sample                                                   | 12-month average | Sample       | 12-month average | Sample       | 12-month average | Sample     | 12-month average | Sample     | 12-month average |
| 1958               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Aug. 15            | 1.048                             | 1.079            | 69                                                       | 72               | 41           | 40               | 3.3          | 5.5              | 28         | 35               | 67         | 53               |
| Sept. 15           | 1.241                             | 1.096            | 10                                                       | 46               | 73           | 39               | 5.5          | 5.6              | 15         | 25               | 70         | 53               |
| Oct. 15            | 1.141                             | 1.098            | 61                                                       | 32               | 85           | 36               | 9.5          | 5.9              | 14         | 13               | 83         | 54               |
| Nov. 15            | 1.089                             | 1.067            | 35                                                       | 27               | 55           | 38               | 8.8          | 6.2              | 30         | 15               | 67         | 56               |
| Dec. 15            | 1.114                             | 1.067            | 9                                                        | 28               | 11           | 37               | 7.9          | 6.5              | 0          | 15               | 71         | 58               |
| 1959               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Jan. 16            | 1.060                             | 1.092            | 0                                                        | 28               | 10           | 37               | 8.9          | 6.6              | 3          | 16               | 65         | 61               |
| Feb. 19            | 1.115                             | 1.094            | 5                                                        | 28               | 8            | 37               | 6.6          | 8.7              | 0          | 16               | 59         | 62               |
| Mar. 16            | 1.106                             | 1.090            | 0                                                        | 28               | 5            | 38               | 6.6          | 6.9              | 0          | 16               | 65         | 63               |
| Apr. 15            | 1.109                             | 1.101            | 3                                                        | 24               | 7            | 39               | 7.6          | 7.2              | 0          | 15               | 62         | 63               |
| May 18             | 1.147                             | 1.110            | 0                                                        | 22               | 20           | 38               | 12.0         | 7.9              | 0          | 14               | 76         | 66               |
| June 15            | 1.136                             | 1.114            | 0                                                        | 22               | 28           | 35               | 14.0         | 8.2              | 0          | 13               | 65         | 66               |
| July 18            | 1.035                             | 1.112            | 12                                                       | 17               | 9            | 29               | 14.6         | 8.5              | 0          | 8                | 81         | 66               |

<sup>1</sup> These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Micromicrocuries per liter

|              |         |
|--------------|---------|
| Iodine 131   | 3,000   |
| Strontium 89 | 7,000   |
| Strontium 90 | 80      |
| Barium 140   | 200,000 |
| Cesium 137   | 150,000 |

Results of composite samples from Overton, Nev., milkshed for period ending July 1959 (available to date)

| Date of collection | Calcium content (grams per liter) |                 | Radioactivity in micromicrocuries per liter <sup>1</sup> |                 |              |                 |              |                 |            |                 |            |                 |
|--------------------|-----------------------------------|-----------------|----------------------------------------------------------|-----------------|--------------|-----------------|--------------|-----------------|------------|-----------------|------------|-----------------|
|                    |                                   |                 | Iodine 131                                               |                 | Strontium 89 |                 | Strontium 90 |                 | Barium 140 |                 | Cesium 137 |                 |
|                    | Sample                            | 5-month average | Sample                                                   | 5-month average | Sample       | 5-month average | Sample       | 5-month average | Sample     | 5-month average | Sample     | 5-month average |
| 1959               |                                   |                 |                                                          |                 |              |                 |              |                 |            |                 |            |                 |
| Mar. 15            | 1.096                             |                 | 1                                                        |                 | 7            |                 | 4.2          |                 | 0          |                 | 31         |                 |
| Apr. 13            | 1.094                             |                 | 0                                                        |                 | 4            |                 | 3.1          |                 | 0          |                 | 30         |                 |
| May 12             | 1.091                             |                 | 0                                                        |                 | 3            |                 | 3.6          |                 | 0          |                 | 26         |                 |
| June 14            | 1.055                             |                 | 4                                                        |                 | 4            |                 | 4.2          |                 | 0          |                 | 36         |                 |
| July 13            | 1.005                             | 1.069           | 0                                                        | 1               | 2            | 4               | 1.6          | 3.4             | 0          | 0               | 57         | 38              |

<sup>1</sup> These limits are the maxima permissible limits for lifetime exposure of population groups to specific radionuclides in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Micromicrocuries per liter

|              |         |
|--------------|---------|
| Iodine 131   | 3,000   |
| Strontium 89 | 7,000   |
| Strontium 90 | 80      |
| Barium 140   | 200,000 |
| Cesium 137   | 150,000 |

Results of composite samples from Sacramento, Calif., milkshed for period ending July 1959

| Date of collection | Calcium content (grams per liter) |                  | Radioactivity in micromicrocuries per liter <sup>1</sup> |                  |              |                  |              |                  |            |                  |            |                  |
|--------------------|-----------------------------------|------------------|----------------------------------------------------------|------------------|--------------|------------------|--------------|------------------|------------|------------------|------------|------------------|
|                    |                                   |                  | Iodine 131                                               |                  | Strontium 89 |                  | Strontium 90 |                  | Barium 140 |                  | Cesium 137 |                  |
|                    | Sample                            | 12-month average | Sample                                                   | 12-month average | Sample       | 12-month average | Sample       | 12-month average | Sample     | 12-month average | Sample     | 12-month average |
| 1958               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Aug. 17            | 1.160                             | 1.131            | 22                                                       | 29               | 24           | 24               | 6.8          | 5.3              | 0          | 17               | 65         | 65               |
| Sept. 17           | 1.161                             | 1.137            | 9                                                        | 29               | 17           | 24               | 3.8          | 5.3              | 0          | 16               | 72         | 67               |
| Oct. 14            | 1.169                             | 1.134            | 12                                                       | 29               | 11           | 23               | 1.4          | 5.4              | 1          | 11               | 39         | 57               |
| Nov. 18            | 1.111                             | 1.131            | 17                                                       | 30               | 18           | 24               | 6.1          | 5.1              | 14         | 8                | 46         | 57               |
| Dec. 14            | 1.106                             | 1.122            | 14                                                       | 31               | 10           | 25               | 4.2          | 5.1              | 6          | 8                | 48         | 58               |
| 1959               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Jan. 15            | 1.150                             | 1.131            | 0                                                        | 31               | 13           | 24               | 4.3          | 5.0              | 0          | 7                | 35         | 57               |
| Feb. 28            | 1.151                             | 1.133            | 3                                                        | 31               | 12           | 25               | 3.9          | 5.0              | 0          | 6                | 46         | 57               |
| Mar. 15            | 1.133                             | 1.131            | 1                                                        | 31               | 58           | 28               | 7.7          | 5.2              | 0          | 6                | 60         | 58               |
| Apr. 19            | 1.148                             | 1.132            | 4                                                        | 31               | 38           | 25               | 7.5          | 5.0              | 0          | 4                | 50         | 54               |
| May 16             | 1.147                             | 1.122            | 0                                                        | 31               | 28           | 24               | 8.6          | 5.4              | 0          | 3                | 55         | 56               |
| June 15            | 1.137                             | 1.133            | 3                                                        | 11               | 10           | 21               | 6.4          | 5.8              | 0          | 2                | 60         | 53               |
| July 14            | 1.039                             | 1.134            | 0                                                        | 7                | 5            | 20               | 4.3          | 5.4              | 0          | 1                | 58         | 54               |

<sup>1</sup> These limits are the maxima permissible limits for lifetime exposure of population groups to specific radionuclides in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Micromicrocuries per liter

|              |         |
|--------------|---------|
| Iodine 131   | 3,000   |
| Strontium 89 | 7,000   |
| Strontium 90 | 80      |
| Barium 140   | 200,000 |
| Cesium 137   | 150,000 |

Results of composite samples from Salt Lake City, Utah, milkshed for period ending July 1959

| Date of collection | Calcium content (grams per liter) |                  | Radioactivity in micromicrocuries per liter <sup>1</sup> |                  |              |                  |              |                  |            |                  |            |                  |
|--------------------|-----------------------------------|------------------|----------------------------------------------------------|------------------|--------------|------------------|--------------|------------------|------------|------------------|------------|------------------|
|                    |                                   |                  | Iodine 131                                               |                  | Strontium 89 |                  | Strontium 90 |                  | Barium 140 |                  | Cesium 137 |                  |
|                    | Sample                            | 12-month average | Sample                                                   | 12-month average | Sample       | 12-month average | Sample       | 12-month average | Sample     | 12-month average | Sample     | 12-month average |
| 1958               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Aug. 14            | 1.108                             | 1.125            | 77                                                       | 174              | 44           | 31               | 4.2          | 4.2              | 20         | 24               | 43         | 50               |
| Sept. 15           | 1.207                             | 1.142            | 14                                                       | 113              | 44           | 35               | 5.0          | 4.2              | 14         | 18               | 48         | 51               |
| Oct. 13            | 1.187                             | 1.143            | 11                                                       | 32               | 28           | 24               | 3.1          | 4.0              | 5          | 8                | 31         | 49               |
| Nov. 14            | 1.162                             | 1.142            | 33                                                       | 34               | 13           | 23               | 5.2          | 4.1              | 4          | 8                | 27         | 49               |
| Dec. 16            | 1.161                             | 1.142            | 8                                                        | 31               | 5            | 23               | 6.1          | 4.3              | 0          | 7                | 39         | 49               |
| 1959               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Jan. 15            | 1.137                             | 1.140            | 2                                                        | 31               | 6            | 23               | 4.5          | 4.4              | 5          | 8                | 34         | 49               |
| Feb. 17            | 1.176                             | 1.147            | 1                                                        | 28               | 5            | 22               | 3.4          | 4.5              | 0          | 8                | 37         | 46               |
| Mar. 16            | 1.176                             | 1.149            | 2                                                        | 28               | 4            | 22               | 4.6          | 4.7              | 0          | 8                | 38         | 43               |
| Apr. 16            | 1.118                             | 1.148            | 6                                                        | 26               | 6            | 23               | 5.4          | 4.7              | 0          | 8                | 32         | 40               |
| May 14             | 1.132                             | 1.147            | 7                                                        | 26               | 32           | 23               | 9.8          | 5.3              | 0          | 7                | 60         | 42               |
| June 15            | 1.123                             | 1.146            | 7                                                        | 27               | 24           | 20               | 11.8         | 5.6              | 0          | 5                | 70         | 42               |
| July 15            | 1.099                             | 1.146            | 0                                                        | 14               | 16           | 19               | 9.4          | 6.0              | 0          | 4                | 61         | 44               |

<sup>1</sup> These limits are the maxima permissible limits for lifetime exposure of population groups to specific radionuclides in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Micromicrocuries per liter

|              |         |
|--------------|---------|
| Iodine 131   | 3,000   |
| Strontium 89 | 7,000   |
| Strontium 90 | 80      |
| Barium 140   | 200,000 |
| Cesium 137   | 150,000 |

Results of composite samples from Spokane, Wash., milkshed for period ending July 1959

| Date of collection | Calcium content (grams per liter) |                  | Radioactivity in micromicrocuries per liter <sup>1</sup> |                  |              |                  |              |                  |            |                  |            |                  |
|--------------------|-----------------------------------|------------------|----------------------------------------------------------|------------------|--------------|------------------|--------------|------------------|------------|------------------|------------|------------------|
|                    | Sample                            | 12-month average | Iodine 131                                               |                  | Strontium 89 |                  | Strontium 90 |                  | Barium 140 |                  | Cesium 137 |                  |
|                    |                                   |                  | Sample                                                   | 12-month average | Sample       | 12-month average | Sample       | 12-month average | Sample     | 12-month average | Sample     | 12-month average |
| 1958               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Aug. 8             | 1.168                             |                  | 68                                                       |                  | 64           |                  | 6.9          |                  | 18         |                  | 93         |                  |
| Sept. 3            | 1.163                             |                  | 11                                                       |                  | 23           |                  | 8.2          |                  | 5          |                  | 78         |                  |
| Oct. 2             | 1.202                             |                  | 8                                                        |                  | 53           |                  | 8.6          |                  | 6          |                  | 72         |                  |
| Nov. 6             | 1.223                             |                  | 87                                                       |                  | 35           |                  | 11.9         |                  | 52         |                  | 72         |                  |
| Nov. 30            | 1.241                             |                  | 30                                                       |                  | 21           |                  | 8.6          |                  | 7          |                  | 84         |                  |
| 1959               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Jan. 2             | 1.208                             |                  | 7                                                        |                  | 20           |                  | 9.1          |                  | 3          |                  | 73         |                  |
| Feb. 3             | 1.183                             |                  | 4                                                        |                  | 16           |                  | 6.3          |                  | 0          |                  | 84         |                  |
| Mar. 2             | 1.236                             |                  | 8                                                        |                  | 6            |                  | 10.9         |                  | 0          |                  | 66         |                  |
| Apr. 6             | 1.172                             |                  | 0                                                        |                  | 15           |                  | 10.5         |                  | 0          |                  | 58         |                  |
| May 5              | 1.184                             |                  | 18                                                       |                  | 90           |                  | 22.6         |                  | 0          |                  | 104        |                  |
| June 1             | 1.182                             |                  | 5                                                        |                  | 54           |                  | 22.1         |                  | 0          |                  | 96         |                  |
| July 6             | 1.224                             | 1.200            | 0                                                        | 10               | 24           | 37               | 18.3         | 12.0             | 0          | 8                | 78         | 80               |

<sup>1</sup> These limits are the maxima permissible limits for lifetime exposure of population groups to specific radionuclides in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

|              |  | Micromicrocuries per liter |
|--------------|--|----------------------------|
| Iodine 131   |  | 3,000                      |
| Strontium 89 |  | 7,000                      |
| Strontium 90 |  | 80                         |
| Barium 140   |  | 200,000                    |
| Cesium 137   |  | 150,000                    |

Results of composite samples from St. George, Utah, milkshed for period ending July 1959 (available to date)

| Date of collection | Calcium content (grams per liter) |                 | Radioactivity in micromicrocuries per liter <sup>1</sup> |                 |              |                 |              |                 |            |                 |            |                 |
|--------------------|-----------------------------------|-----------------|----------------------------------------------------------|-----------------|--------------|-----------------|--------------|-----------------|------------|-----------------|------------|-----------------|
|                    | Sample                            | 4-month average | Iodine 131                                               |                 | Strontium 89 |                 | Strontium 90 |                 | Barium 140 |                 | Cesium 137 |                 |
|                    |                                   |                 | Sample                                                   | 4-month average | Sample       | 4-month average | Sample       | 4-month average | Sample     | 4-month average | Sample     | 4-month average |
| 1959               |                                   |                 |                                                          |                 |              |                 |              |                 |            |                 |            |                 |
| Mar. 20            | 1.161                             |                 | 3                                                        |                 | 2            |                 | 6.6          |                 | 0          |                 | 33         |                 |
| Apr. 11            | 1.104                             |                 | 0                                                        |                 | 0            |                 | 5.6          |                 | 0          |                 | 32         |                 |
| May 13             | 1.126                             |                 | 1                                                        |                 | 15           |                 | 5.7          |                 | 0          |                 | 40         |                 |
| June 12            | 1.137                             | 1.132           | 5                                                        | 2               | 30           | 11              | 7.9          | 6.3             | 0          | 0               | 65         | 42              |
| No report          |                                   |                 |                                                          |                 |              |                 |              |                 |            |                 |            |                 |

<sup>1</sup> These limits are the maxima permissible limits for lifetime exposure of population groups to specific radionuclides in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

|              |  | Micromicrocuries per liter |
|--------------|--|----------------------------|
| Iodine 131   |  | 3,000                      |
| Strontium 89 |  | 7,000                      |
| Strontium 90 |  | 80                         |
| Barium 140   |  | 200,000                    |
| Cesium 137   |  | 150,000                    |

Results of composite samples from St. Louis, Mo., milkshed for period ending July 1959

| Date of collection | Calcium content (grams per liter) |                  | Radioactivity in micromicrocuries per liter <sup>1</sup> |                  |              |                  |              |                  |            |                  |            |                  |
|--------------------|-----------------------------------|------------------|----------------------------------------------------------|------------------|--------------|------------------|--------------|------------------|------------|------------------|------------|------------------|
|                    | Sample                            | 12-month average | Iodine 131                                               |                  | Strontium 89 |                  | Strontium 90 |                  | Barium 140 |                  | Cesium 137 |                  |
|                    |                                   |                  | Sample                                                   | 12-month average | Sample       | 12-month average | Sample       | 12-month average | Sample     | 12-month average | Sample     | 12-month average |
| 1958               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Aug. 19            | 1.260                             | 1.264            | 61                                                       | 220              | 263          | 115              | 14.1         | 10.7             | 113        | 98               | 109        | 72               |
| Sept. 16           | 1.303                             | 1.272            | 19                                                       | 141              | 283          | 118              | 15.4         | 11.2             | 68         | 56               | 104        | 76               |
| Oct. 15            | 1.271                             | 1.272            | 38                                                       | 70               | 138          | 118              | 12.2         | 11.4             | 14         | 46               | 71         | 77               |
| Nov. 18            | 1.260                             | 1.270            | 123                                                      | 80               | 168          | 136              | 20.1         | 12.5             | 38         | 48               | 74         | 80               |
| Dec. 16            | 1.274                             | 1.267            | 23                                                       | 82               | 94           | 130              | 15.6         | 13.2             | 8          | 48               | 75         | 82               |
| 1959               |                                   |                  |                                                          |                  |              |                  |              |                  |            |                  |            |                  |
| Jan. 17            | 1.329                             | 1.268            | 7                                                        | 63               | 77           | 134              | 18.6         | 14.1             | 14         | 48               | 64         | 84               |
| Feb. 17            | 1.282                             | 1.266            | 0                                                        | 83               | 94           | 140              | 19.6         | 15.1             | 4          | 48               | 73         | 80               |
| Mar. 16            | 1.225                             | 1.262            | 4                                                        | 83               | 130          | 150              | 22.6         | 16.2             | 5          | 48               | 92         | 80               |
| Apr. 15            | 1.301                             | 1.266            | 0                                                        | 75               | 162          | 160              | 37.3         | 18.2             | 0          | 44               | 100        | 83               |
| May 19             | 1.294                             | 1.264            | 0                                                        | 75               | 140          | 163              | 34.6         | 20.3             | 0          | 43               | 165        | 90               |
| June 17            | 1.277                             | 1.260            | 6                                                        | 75               | 77           | 139              | 11.2         | 20.0             | 0          | 39               | 104        | 90               |
| July 19            | 1.123                             | 1.255            | 0                                                        | 28               | 27           | 135              | 17.6         | 19.9             | 0          | 20               | 111        | 96               |

<sup>1</sup> These limits are the maxima permissible limits for lifetime exposure of population groups to specific radionuclides in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

|              |  | Micromicrocuries per liter |
|--------------|--|----------------------------|
| Iodine 131   |  | 3,000                      |
| Strontium 89 |  | 7,000                      |
| Strontium 90 |  | 80                         |
| Barium 140   |  | 200,000                    |
| Cesium 137   |  | 150,000                    |

ATOMIC ENERGY COMMISSION,  
Washington, D.C., October 6, 1959.

### THREE FEDERAL AGENCIES PLAN RESEARCH TO HELP DAIRIES REMOVE STRONTIUM 90 FROM MILK

A joint research effort to develop dairy-plant methods of removing strontium 90 from milk is being planned by the U.S. Atomic Energy Commission, the U.S. Public Health Service, and the U.S. Department of Agriculture.

The levels of radioactive fallout from past nuclear testing do not justify action to decontaminate milk supplies. The research is designed to provide practical answers to problems that might arise in the future.

The proposal to develop practical dairy-plant scale methods of removing strontium 90 from milk grew out of laboratory studies sponsored by the Atomic Energy Commission at the University of Tennessee as well as by Canadian and British scientists. These showed that it is possible, on a laboratory scale, to remove strontium 90 from milk through the use of certain chemicals known technically as ion exchange resins.

Ion exchange resins duplicate a natural phenomenon in soils. Strontium 90 that enters the soil is absorbed on soil particles and enters into reactions between the soil and plant root. However, only a little strontium 90 gets into the plant in this way. It is now known that much of the strontium 90 that does get into plants is absorbed through their leaves. This can be ingested by ruminants. The best evidence is that the animals take into their systems about 5 percent of the strontium 90 ingested and that a dairy cow secretes in her milk about 1 percent of the strontium 90 she consumes each day. The laboratory tests already done indicate that more than 90 and possibly more than 95 percent of the strontium 90 that gets into milk can be removed by ion exchange resins.

The research will be conducted in a pilot plant at the Agricultural Research Center at Beltsville, Md.

## APPENDIX C

## AEC QUARTERLY REPORTS

U.S. ATOMIC ENERGY COMMISSION,  
Washington, D.C., September 8, 1959.

## FIRST QUARTER REPORT

On May 5 Chairman John A. McCone, of the U.S. Atomic Energy Commission, announced that the Commission would issue "regular quarterly releases of all fallout information" as such information is gathered by scientists of the Commission and its contractors. The attached statement has been prepared by the Commission's staff pursuant to this announcement and is being issued for the information of the public.

During the time since Chairman McCone's announcement, a study of the organization of Federal radiological health activities was made under the leadership of the Bureau of the Budget. On completion of this study, President Eisenhower issued an Executive order establishing a Federal Radiation Council to advise the President in the field of radiological health. He also directed that the Department of Health, Education, and Welfare have primary responsibility within the executive branch for the collation, analysis, and interpretation of data on environmental radiation levels.

The Atomic Energy Commission will continue to issue this type of data on a quarterly basis, although new procedures developed by the Federal Radiation Council may later supersede this report. HEW collation, analysis, and interpretation of this and other information from AEC and other sources will then serve as the basis for the HEW Secretary's advice to the President and the public. Tabulations of detailed data on domestic and worldwide fallout levels are contained in quarterly reports issued by the Commission's Health and Safety Laboratory, New York, and published for sale through the Office of Technical Services, U.S. Department of Commerce.

QUARTERLY STATEMENT ON FALLOUT BY THE U.S. ATOMIC ENERGY COMMISSION,  
SEPTEMBER 1959

## Summary

This statement provides the latest information received by the Atomic Energy Commission on (1) surface air radioactivity levels, (2) strontium 90 levels in U.S. milk, (3) production of carbon 14 in nuclear explosions, and (4) strontium 90 removal from milk. In addition, an appendix considers in some detail the subject of areas where relatively high fallout has occurred.

The latest data on concentration of fission product radioactivity in surface air indicate a decrease after several months of generally rising levels. The concentrations of fission products in the lower atmosphere during May and June, as measured at four stations in the Eastern United States, decreased to about the same levels as were observed in January and February. The June levels were the lowest since September 1958.

The latest data on strontium 90 levels in milk in the United States showed increases in some areas above concentrations noted previously and decreases in others. As announced by the U.S. Public Health Service on July 13, 1959, the strontium 90 concentration in milk from the St. Louis, Mo., area was 37.3 micromicrocuries per liter in April. The St. Louis levels dropped to 34.6 micromicrocuries per liter in May and to 11.2 micromicrocuries per liter in June. These values were compared by the Public Health Service with a maximum permissible level of 80 micromicrocuries per liter derived from recommendations for lifetime exposure of population groups to strontium 90 in water which had been made by the National Committee on Radiation Protection and Measurements. The Public Health Service noted that this limit has been generally accepted as applicable to milk.

Increases in strontium 90 in milk presumably reflect the higher fallout rate occurring during the early part of 1959. If the fallout peak has passed, these levels may decrease during the next few months.

Using ion exchange techniques, it has been possible in the laboratory to remove up to 94 percent of the strontium from skim milk without loss of calcium from the milk. Strontium may be removed from cream by a washing process.

During the past 2 years increasing attention has been paid to the genetic hazards of carbon 14 produced by fission and fusion detonations. The most recent information suggests that the number of carbon 14 atoms produced per megaton of total yield (equivalent in energy release to a million tons of TNT) in past U.S. nuclear tests is about two-thirds of the number previously estimated.

As noted in appendix A, studies have been made of radioactivity in three areas which have received special attention for various reasons. These areas are (1) California, (2) Nevada and Utah, and (3) the Dakotas and Minnesota.

Unusually high concentrations of radioactivity in air and water occurred in California in 1958. Radiochemical analyses demonstrated that these were transient levels consisting largely of relatively short-lived radioisotopes from tests held shortly before the fallout occurred. Observed concentrations of strontium 90 and other long-lived radioisotopes in California are lower than the U.S. average.

Similar periods of high concentrations of fresh fallout radioactivity have occurred in parts of Nevada and Utah and, less frequently, in other States to the north and east following continental tests. Especially in the more northerly areas, during 1957 and 1958 fallout from these and other sources led to relatively high concentrations of strontium 90 in vegetation, reflected in high concentrations in milk. An intensive study in North Dakota shows that the total amount of strontium 90 in the soil to date is about equal to the average for the United States as a whole, and suggests that the high concentrations on vegetation were due, in part at least, to retention of material reaching the plants from air and rain.

## Surface air radioactivity levels

The latest data (May and June 1959) on the concentrations of gross beta radioactivity in the lower atmosphere indicate a decrease after several months of generally rising levels.<sup>1</sup> Ground-level air filter measurements made at four stations<sup>2</sup> in the Eastern United States by the Naval Research Laboratory show roughly a 30 percent decrease from 9-11 micromicrocuries per cubic meter of air in April to 6-7 in May and a further decrease to 2-4 in June. The May levels are comparable to the averaged levels observed in January and February 1959 at the four NRL stations and at the 40 continental U.S. stations operated by U.S. Public Health Service laboratories, and the June levels are the lowest since September 1958.

Levels of gross beta radioactivity in surface air in the Southern Hemisphere have continued to be 50 to 100 times lower than those quoted above for latitudes

## Mean values, gross beta activity collected by air filtration

[Micromicrocuries per cubic meter of air<sup>1</sup>]

| Month (1959)  | Station        |                   |                     |                   |
|---------------|----------------|-------------------|---------------------|-------------------|
|               | Miami,<br>Fla. | Columbia,<br>S.C. | Washington,<br>D.C. | Bedford,<br>Mass. |
| January.....  | 8.6            | 7.8               | 6.3                 | 4.5               |
| February..... | 6.8            | 8.1               | 5.8                 | 6.6               |
| March.....    | 11.1           | 8.7               | 6.9                 | 6.4               |
| April.....    | 11.4           | 9.5               | 9.3                 | 8.7               |
| May.....      | 6.4            | 7.1               | 5.5                 | 7.0               |
| June.....     | 2.1            | 3.0               | 3.9                 | 2.6               |

<sup>1</sup> These data were reported by the U.S. Naval Research Laboratory in units of disintegrations per minute per cubic meter of air and have been converted for this table.

<sup>2</sup> Measurements corrected for radiation decay of short-lived natural radioactivity.

<sup>3</sup> Bedford, Mass., Washington, D.C., Columbia, S.C., and Miami, Fla.

tudes of the United States. Levels in Alaska (4.4 to 5.6 in April)<sup>1</sup> and Hawaii (4.9 in April)<sup>2</sup> have also been somewhat lower than in the continental United States (3 to 12 in April).<sup>3</sup> Indications are that the rate of transfer to the lower atmosphere of radioactive debris injected into the stratosphere during the high-yield weapons tests carried out by the U.S.S.R. during the fall of 1958 has passed through its maximum and is on the decline. This transfer appears to have occurred in such a way as to lead to peak concentrations of radioactivity in surface air in the Southern United States and elsewhere in the same latitudes.

#### Strontium 90 levels in U.S. milk

The AEC Health and Safety Laboratory, New York City, is currently analyzing samples of milk from the following three locations for strontium 90:

Mandan, N. Dak. (powdered buttermilk)

Perry, N.Y. (powdered milk)

New York City (liquid milk)

The Public Health Service analyzes samples of milk from the following 12 locations for strontium 90, cesium 137, iodine 131, strontium 89, and barium 140:

|                                |                      |
|--------------------------------|----------------------|
| Atlanta, Ga.                   | Overton, Nev.        |
| Austin, Tex.                   | Sacramento, Calif.   |
| Chicago, Ill.                  | Salt Lake City, Utah |
| Cincinnati, Ohio               | Spokane, Wash.       |
| Fargo, N. Dak.—Moorhead, Minn. | St. George, Utah     |
| New York, N.Y.                 | St. Louis, Mo.       |

The Public Health Service data<sup>4</sup> show that St. Louis, Mo., has exhibited rising strontium 90 levels in milk beginning in early 1959 with indications of decrease in recent months. The level increased to 37.3 micromicrocuries per liter in April, one of the three highest values reported for milk in the United States as far as AEC records show. (Approximately the same concentrations were reported in North Soo, N. Dak., in May 1958<sup>5</sup> and in Panguitch, Utah, in September 1957.<sup>6</sup> The levels at St. Louis decreased to 34.6 micromicrocuries per liter in May and to 11.2 micromicrocuries per liter in June.) Levels in milk were compared by the Public Health Service with a maximum permissible level of 80 micromicrocuries per liter derived from recommendations for lifetime exposure of population groups to strontium 90 in water which had been made by the Nation Committee on Radiation Protection and Measurements. The Public Health Service noted that this limit has been generally accepted as applicable to milk.

The following table permits comparison of strontium 90 levels in milk at three locations sampled in 1959 by the Commission's Health and Safety Laboratory:

Strontium 90 levels in milk, 1959

[Micromicrocuries per gram of calcium]

| Sampling month | New York, N.Y. (liquid milk) | Perry, N.Y. (powdered milk) | Mandan, N. Dak. (powdered buttermilk) |
|----------------|------------------------------|-----------------------------|---------------------------------------|
| January.....   | 8.2                          | 8.1                         | 20.8                                  |
| February.....  | 8.4                          | 7.8                         | 18.4                                  |
| March.....     | 8.1                          | 6.8                         | 22.9                                  |
| April.....     | 7.7                          | 7.2                         | ( <sup>7</sup> )                      |

<sup>1</sup> Analysis in process.

**Removal of strontium from milk.**—Methods for removal of radioactive strontium from milk would be vitally important if gross contamination were to occur, for instance, from nuclear accidents or in the event of nuclear warfare.

<sup>2</sup> Latest data available.

<sup>3</sup> Based on 40 PHS stations and 4 NRL stations.

<sup>4</sup> USPHS monthly report released Aug. 20, 1958. Available from USPHS free of charge.

<sup>5</sup> Annex B, table I.

<sup>6</sup> Testimony by Kermit Larson, University of California School of Medicine, during hearings on fallout conducted by Joint Committee on Atomic Energy, U.S. Congress, May 5-8, 1958.

Laboratory studies have been conducted at the University of Tennessee Atomic Energy Agricultural Research Laboratory, under contract with the AEC. The treatment is similar to that given water in home water softeners.

The fractions of strontium and calcium removed from the milk by such processes depends upon the kinds and quantities of ion exchange resins used and upon other factors. Using calcium based resins, with proper adjustment of experimental factors, it was found possible to remove up to 94 percent of strontium from separated milk without loss of calcium. Other effects of this treatment on the quality of the milk will be studied, although it can be predicted with reasonable certainty that the changes are small. Radioactive strontium associated with the cream may be removed by repeated dilution of the cream with water followed by separation of the cream from the water.

The results of this study were presented at the 54th annual meeting of the American Dairy Science Association, June 15, and a report is being prepared by the research team for publication.

It should be emphasized that these are preliminary results obtained from laboratory scale procedures which were initiated to determine the feasibility of the procedures. Developmental studies will be undertaken to establish the practicality of strontium 90 removal from milk on a larger scale and to provide the basis for estimating costs at the level of commercial dairy operations.

#### Production of carbon 14 in nuclear explosions

A 1958 report<sup>1</sup> on the biological hazard to man of carbon 14 from nuclear test explosions pointed out that for U.S. nuclear weapons of all types, roughly equal quantities of carbon 14 are produced per megaton of total (fission and fusion) weapon yield. A value of 3.2 by 10<sup>10</sup> carbon 14 atoms per megaton of total yield was cited in the report. More up-to-date information suggests that for U.S. weapons tests, approximately 2 by 10<sup>10</sup> atoms of carbon 14 per megaton of total (not fission alone) yield are formed for airbursts. The newer estimate is about two-thirds of the old. For surface bursts, this number should be divided by two because about one-half of the escaping neutrons would be captured in surface materials rather than air, including radioactivity in these surface materials.

Expressed in activity units, 2 by 10<sup>10</sup> atoms of carbon 14 is about 20,000 curies or 0.02 megacuries. Expressed in weight units, 2 by 10<sup>10</sup> atoms of carbon 14 is about 4.7 kilograms.

A factor of uncertainty of about two is to be applied to the above value, that is, the actual value should lie within one-half to two times the value given. For this reason, it is not particularly appropriate to revise the hazards estimates given in the reference mentioned above.

The value given here was used in testimony by Dr. Lester Machta, U.S. Weather Bureau, before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy in recent hearings on the biological and environmental effects of nuclear war.

#### APPENDIX A

##### AREAS OF GREATER THAN AVERAGE RADIOACTIVITY

(Information in app. A was same as that provided to Joint Committee in letter dated May 18, 1959 (see p. 2114), regarding "hotspot" problem.)

U.S. Atomic Energy Commission,  
Washington, D.C., October 8, 1959.

#### SECOND QUARTER REPORT

The second quarterly statement, which is attached, is being issued at this time to coincide with the issuance of HASL-69, the latest quarterly strontium report by the Commission's New York Health and Safety Laboratory. HASL-69, which may be purchased from the Office of Technical Services, U.S. Department of Com-

<sup>1</sup> "The Biological Hazard to Man of Carbon 14 From Nuclear Weapons," WASH-1008, M. R. Zelle, H. Hollister, J. R. Totter, September 1958, available from the Office of Technical Services, Department of Commerce, Washington 25, D.C., price \$0.50. Reprinted in Science, vol. 128, pp. 1490-95, Dec. 12, 1958.

merce, for \$3.50, contains detailed data which are summarized in the attached statement.

In addition to information from Commission laboratories and Commission contractors, the attached statement contains certain data from the Department of Health, Education, and Welfare and other sources with particular relevance to the other data contained in this statement.

The Commission will continue to issue this type of data on a quarterly basis, although new procedures developed by the Federal Radiation Council may later supersede these quarterly releases.

QUARTERLY STATEMENT ON FALLOUT BY THE U.S. ATOMIC ENERGY COMMISSION,  
OCTOBER 1959

SUMMARY

This statement summarizes the latest information received by the Atomic Energy Commission on (1) surface air radioactivity, (2) strontium 90 levels in milk and other foods, (3) fission product radioactivity in soils, (4) cesium 137 levels in people and milk, (5) strontium 90 in milk and bones of Nevada cattle, and (6) monthly fallout collections.<sup>1</sup>

Concentrations of total fallout beta radioactivity in surface air have decreased somewhat in both hemispheres in May compared with April. Air concentrations at four stations in the eastern United States during July were about one-third to one-half the June values and showed a continuation of this decrease which began in May and continued through June and July.

Monthly fission product gamma radioactivity levels in soils at Argonne National Laboratory for March to July indicate an increase in gamma radioactivity in this soil to a peak in May. Estimated gamma radiation dose rates for June and July were somewhat lower than the May values but over twice the levels for September 1958. The fission product gamma radioactivity in terms of millicuries per square mile in the soil peaked in June.

Strontium 90 levels in milk samples from New York City and Perry, N.Y., for May and June were higher than for April. The New York City level for June of 26.2 strontium units (micromicrocuries of strontium 90 per gram of calcium) is the highest reported for that location to date although not as high as earlier at other locations. The milk level in Mandan, N. Dak., in May of 47.5 strontium units is one of the highest reported to date so far as AEC records show. The level decreased to 22.2 strontium units in July. Samples of white and whole wheat flour and bread in New York during April differed little from February samples in strontium 90 content. Wheat samples (1958 crop) from 9 U.S. wheat producing States range in strontium 90 content from 21 to 133 micromicrocuries per kilogram, which do not differ greatly from that previously reported for Minnesota (1956-58) and North Dakota (1958) wheat samples. Analyses of Minnesota 1945-58 seed corn showed strontium 90 levels too low to be quantitatively detectable. Strontium 90 levels for samples collected in Nebraska in micromicrocuries per kilogram were 5.6 for fresh milk (May 1959), 8.1 for dried milk (February 1959) (computed as liquid milk), and 0.8 to 2.5 for corn (fall 1958 harvest).

Levels of cesium 137 in the United States so far in 1959 ranged from 12 to 170 cesium units (micromicrocuries of cesium 137 per gram of potassium) in people and 7 to 297 cesium units in nonfat dry milk. During 1958 the average milk value was 50 cesium units with some values as high as 250. The 1958 average for people was 67 cesium units. For comparison, values were also calculated for natural radioactivity from potassium 40 in the upper and lower limit samples. Cesium 137 appeared to be about one-twentieth to one-fourth the potassium 40 values in people and about one and one-hundredth to two-fifths the potassium 40 values in dry milk. At present no conclusions as to levels in specific areas or age groups can be made. A summary and evaluation will be made after completion of 1959 sampling.

<sup>1</sup> The Commission will continue to issue this type of data on a quarterly basis, although new procedures developed by the Federal Radiation Council may later supersede these quarterly releases. The Department of Health, Education, and Welfare will collate, analyze, and interpret this and other information from AEC and other sources and make periodic releases to the public.

Cattle bone levels at three locations in Nevada during 1958 ranged from 3.7 (rib) to 44.8 (femur) strontium units, both at the Nevada test site. The highest of the Nevada milk levels for May and November 1958 was 5 strontium units in May. This suggests that values to be expected in persons living in this area would be well below the values in cattle bone.

Included also are some plutonium data. As can be seen, plutonium adds a measurable but small portion to the dose from fission product fallout.

Surface air radioactivity levels

Ground level air filter measurements made at the four stations in the eastern United States by the Naval Research Laboratory (see table on p. 4) show a further decrease in gross or total beta radioactivity from about 2 to 4 micromicrocuries per cubic meter in June to about 0.75 to 1.5 in July.

Mean values, gross fallout beta activity collected by air filtration

(Micromicrocuries per cubic meter of air<sup>1</sup>)

| Month (1959) | Station     |                |                  |                |
|--------------|-------------|----------------|------------------|----------------|
|              | Miami, Fla. | Columbus, S.C. | Washington, D.C. | Bedford, Mass. |
| April.....   | 11.4        | 9.8            | 9.3              | 8.7            |
| May.....     | 6.4         | 7.1            | 6.5              | 7.0            |
| June.....    | 2.1         | 3.0            | 3.9              | 2.6            |
| July.....    | .74         | .80            | 1.15             | 1.43           |

<sup>1</sup> These data were reported by the U.S. Naval Research Laboratory in units of disintegrations per minute per cubic meter of air and have been converted for this table.

Levels of gross or total fallout beta radioactivity have decreased somewhat in both hemispheres in May compared with April levels. Levels for April and May were as follows:

Gross fallout beta radioactivity

(Micromicrocuries per cubic meter)

|                                              | April             | May <sup>1</sup> |
|----------------------------------------------|-------------------|------------------|
| Alaska (3 stations).....                     | 4.4 to 5.6.....   | 3.7 to 5.0.      |
| Hawaii (1 station).....                      | 4.3.....          | 2.6.             |
| Continental United States <sup>2</sup> ..... | 3 to 12.....      | 2.6 to 10.5.     |
| Southern Hemisphere <sup>3</sup> .....       | 0.03 to 0.14..... | 0.03 to 0.11.    |

<sup>1</sup> Latest data available.

<sup>2</sup> 43 PHS stations and 4 NRL stations.

<sup>3</sup> 8 NRL stations.

Argonne National Laboratory, gamma activity in soil

Fission product radioactivity has been determined at Argonne National Laboratory from soil samples using gamma ray spectroscopy. Analyses for the gamma emitters included zirconium 95-niobium 95, cesium 137, ruthenium 106, ruthenium 103, cerium 141, and cerium 144. Results of these monthly analyses for March-July 1959 are shown in table I with data for September 1958 for comparison. The resulting dose rates (theoretically computed from table I) associated with these fission products are shown in table II. Soil samples were taken to a depth of 6 inches.<sup>1</sup>

<sup>1</sup> These are theoretical calculated dose rates based on the assumption that the radioactive elements per unit area were placed on an equal area of an absolutely flat surface of an infinite size, that the entire surface contained the same level of activity, and that the dose rates were then measured 3 feet above that plane surface. Actually the dose rates 3 feet above the earth where the samples were taken would be lower than these calculated dose rates.

TABLE I.—Fission product radioactivity in soil at Argonne National Laboratory in millicuries per square mile

| Isotope                               | Half life      | 1958—<br>September | 1959  |       |       |       |       |
|---------------------------------------|----------------|--------------------|-------|-------|-------|-------|-------|
|                                       |                |                    | March | April | May   | June  | July  |
| Zr <sup>94</sup> and Nb <sup>94</sup> | 66 and 35 days | 315                | 731   | 980   | 1,043 | 917   | 756   |
| Cs <sup>137</sup>                     | 27 years       | 82                 | 128   | 135   | 141   | 147   | 152   |
| Ru <sup>106</sup>                     | 1 year         | 210                | 624   | 812   | 881   | 1,173 | 1,202 |
| Ru <sup>106</sup>                     | 40 days        | 80                 | 331   | 230   | 186   | 120   | 88    |
| Ce <sup>144</sup>                     | 32 days        | 50                 | 480   | 320   | 268   | 182   | 113   |
| Ce <sup>144</sup>                     | 290 days       | 270                | 1,127 | 1,450 | 1,533 | 1,704 | 1,812 |
| Total                                 |                | 1,322              | 4,232 | 4,916 | 5,005 | 5,160 | 4,879 |

TABLE II.—Dose rate from fission product activity in soil at Argonne National Laboratory in microrads per hour (estimated from table I)

| Isotope                               | 1958—<br>September | 1959  |       |      |      |      |
|---------------------------------------|--------------------|-------|-------|------|------|------|
|                                       |                    | March | April | May  | June | July |
| Zr <sup>94</sup> and Nb <sup>94</sup> | 2.00               | 4.64  | 6.22  | 6.82 | 5.82 | 4.80 |
| Cs <sup>137</sup>                     | .21                | .32   | .34   | .36  | .37  | .38  |
| Ru <sup>106</sup>                     | .18                | .53   | .69   | .75  | 1.03 | 1.03 |
| Ru <sup>106</sup>                     | .17                | .60   | .48   | .39  | .26  | .18  |
| Ce <sup>144</sup>                     | .04                | .13   | .07   | .06  | .04  | .03  |
| Ce <sup>144</sup>                     | .05                | .21   | .27   | .28  | .31  | .33  |
| Total                                 | 2.62               | 6.52  | 8.07  | 8.46 | 7.79 | 6.75 |

**Strontium 90 levels in U.S. milk**

Strontium 90 levels in milk at three locations sampled in 1959 by the Commission's Health and Safety Laboratory are given in the table below.

**Strontium 90 levels in milk, 1959**

[Micromicrocuries per gram of calcium or strontium units]

| Sampling month | New York, N.Y. (liquid milk) | Perry, N.Y. (powdered milk) | Mandan, N. Dak. (powdered buttermilk) |
|----------------|------------------------------|-----------------------------|---------------------------------------|
| January        | 8.2                          | 8.1                         | 20.8                                  |
| February       | 6.4                          | 7.6                         | 16.4                                  |
| March          | 8.1                          | 6.6                         | 23.9                                  |
| April          | 7.7                          | 7.2                         | 27.8                                  |
| May            | 13.4                         | 8.9                         | 47.6                                  |
| June           | 26.2                         | 8.9                         | 37.9                                  |
| July           | 14.4                         | 7.0                         | 22.2                                  |

The June sample from New York City reported here as 26.2 strontium units was higher than any previously reported for that station. The value for New York City liquid milk reported by the Public Health Service for June was 14.0 micromicrocuries per liter, very nearly equal to 14 strontium units. This suggests a possible difference in source of the two samples. The July sample for New York City dropped to 14.4 strontium units, about half the June value. The May sample for Mandan is the highest value reported for milk in the United States as far as AEC records show. By July, however, the level had dropped to about that of last winter.

Levels in milk were compared by the Public Health Service with a maximum permissible level of 80 micromicrocuries per liter derived from recommendations for lifetime exposure of population groups to strontium 90 in water which had been made by the National Committee on Radiation Protection.

**Strontium 90 in New York bread and flour**

Data for strontium 90 in flour and bread samples collected in New York City during May 1959 were released on August 22, 1959.<sup>2</sup> The May data indicate that strontium 90 levels in two samples of whole wheat bread (37 to 59 micromicrocuries per kilogram) were about five times the levels in two white bread samples (12 micromicrocuries per kilogram) obtained at the same time. The level in a single sample of whole-wheat flour was 189, compared to 12.8 in a sample of white flour. The values for the white bread sampled in May are somewhat higher than the February ones; however, the values for the whole wheat bread sampled in May are considerably lower than the February values. The levels in the flour sampled in May differed little from those sampled in February.

As has been previously discussed,<sup>1</sup> in computing the relationships between strontium 90 levels in foods and maximum permissible levels it is necessary to consider the entire diet over a matter of many months. The significance of concentrations in single items of food, such as whole-wheat bread, depends upon the extent to which these contribute to the total diet.

**Strontium 90 in wheat**

The Health and Safety Laboratory has completed strontium 90 analyses of samples of 1958 wheat and seed corn from U.S. wheat-producing States which were provided by Dr. R. S. Caldecott, of the University of Minnesota.<sup>4</sup> Some North Dakota wheat data were discussed in the September "Quarterly Statement on Fallout." The levels of strontium 90 observed in 1958 wheat from nine States ranged from 21 to 133 micromicrocuries per kilogram.

The results of strontium 90 analyses of samples of seed corn from Minnesota indicated levels too low to be quantitatively detected. Seed-corn samples included yearly lots of corn from 1945 to 1958. Corn apparently accumulates relatively small amounts of strontium 90.

**Nebraska data**

Samples of milk and corn were collected in Nebraska during May 1959. The results of strontium 90 analyses of these samples are shown below:

| Sample                               | Micromicrocuries of Sr <sup>90</sup> per kilogram (approximately) | Micromicrocuries of Sr <sup>90</sup> per gram of calcium |
|--------------------------------------|-------------------------------------------------------------------|----------------------------------------------------------|
| Fresh milk (Lincoln) May 26, 1959    | 5.0                                                               | 5.6±0.5                                                  |
| Dried milk (processed February 1959) | 8.1                                                               | 8.1±0.5                                                  |
| Corn (fall harvest 1958)             | 2.5                                                               | 15.8±7.0                                                 |
| Do.                                  | .8                                                                | 4.9±6.3                                                  |

<sup>1</sup> Computed as liquid milk.

It should be noted that the very low calcium and strontium 90 content of the corn samples leads to large uncertainties as indicated. The levels shown above are within the range expected.

**Radioactivity in hay and ensilage**

Analyses by the Food and Drug Administration<sup>5</sup> of hay and ensilage samples from 19 States during 1958-59 indicate a wide range of total beta radioactivity from fallout. Levels ranged from 74,000 micromicrocuries of total beta radioactivity per kilogram of alfalfa hay in Minnesota (August-October 1958) to 270 for sweet corn ensilage in Wisconsin (September-October 1958). Four samples of alfalfa hay were analyzed for strontium 90 content. Levels ranged from 138 to 806 micromicrocuries of strontium 90 per kilogram, or 4 to 9 percent of the total beta levels. Strontium 90 concentrations in milk in these areas will be less than those in hay and ensilage.

<sup>2</sup> AEC Press Release R-141, Aug. 22, 1959.

<sup>3</sup> HASL-65, John H. Harley, "Dietary Strontium 90 Estimates for the United States."

<sup>4</sup> HASL-69, p. 129.

<sup>5</sup> Statement by Secretary Flemming, Department of HEW, news conference, Aug. 13, 1959.



*Cesium 137 in people and milk*

Data for cesium 137 in more than 200 people from 25 States and in more than 1,000 samples of milk from 37 locations in 28 States collected in the United States in 1959 through August are presented. These gamma radiation measurements at the Los Alamos Scientific Laboratory have been reported in HASL-69. Previous tabulations and evaluations have been reported in HASL-42 and in the statement of Dr. Wright Langham during the hearings on Radioactive Fallout, May 5-8, 1959, as well as in scientific journals.

Because of the biochemical similarity of cesium and potassium, cesium 137 levels are conveniently expressed as micromicrocuries of cesium 137 per gram of potassium (cesium units). U.S. samples of nonfat dry milk ranged from 7 to 297 cesium units. During 1959 the average milk value was 50 cesium units with some samples as high as about 250. The 1959 levels in people in the United States ranged from 12 to 170 cesium units. The 1958 average for the United States was 67 cesium units. Cesium 137 data for 1959 continue to be obtained.

In the table on page 10 cesium 137 values are compared with those of potassium 40, an isotope of natural potassium found in nature. The calculated natural potassium 40 levels are seen to be higher than are the cesium 137 levels. Natural potassium contains 0.012 percent potassium 40. The levels reported so far include a wide range of ages and location of samples and no systematic variations of concentrations of cesium 137 and potassium 40 with age or location are apparent. A summary and evaluation of the 1959 data will be made by the investigators on completion of 1959 sampling.

*Comparison of cesium 137 and potassium 40 levels*

| Sample                            | Cesium units <sup>1</sup> | Micromicrocuries of Cs <sup>137</sup> per kilogram | Micromicrocuries of K <sup>40</sup> per kilogram | Cs <sup>137</sup> /K |
|-----------------------------------|---------------------------|----------------------------------------------------|--------------------------------------------------|----------------------|
| Highest Cs <sup>137</sup> -milk   | 297                       | 5,400                                              | 12,300                                           | 0.44                 |
| Lowest Cs <sup>137</sup> -milk    | 7                         | 120                                                | 11,500                                           | .01                  |
| Highest Cs <sup>137</sup> -people | 170                       | 328                                                | 1,290                                            | .26                  |
| Lowest Cs <sup>137</sup> -people  | 37                        | 68                                                 | 1,230                                            | .05                  |

<sup>1</sup> Micromicrocuries of Cs<sup>137</sup> per gram of potassium.

*Strontium 90 in milk and bones of Nevada cattle*

Investigators at the University of Nevada, under contract with AEC have reported strontium 90 levels in milk and bones of cattle collected in Nevada during 1958. Strontium analyses were performed by the health and safety laboratory. Nevada samples were collected at Knoll Creek, Delamar Valley, and the Nevada test site. Cattle bone levels at these locations ranged from 3.7 (rib) to 44.8 (femur) micromicrocuries of strontium 90 per gram of calcium (strontium units) both extremes from the Nevada test site. Milk levels determined in Knoll Creek and Delamar Valley samples in May and November 1958 showed the value for May at Knoll Creek of 5 strontium units to be the highest. Studies conducted in other areas of the United States have suggested that human bones accumulate less strontium 90 than animal bones in the same area. The Nevada milk and bone data also suggest that values to be expected in persons living in Nevada would be well below the values in cattle.

*Monthly fallout collections*

Monthly fallout collections are made at each of worldwide network of stations set up by the Health and Safety Laboratory and analyses are made for strontium 90, strontium 89 and tungsten 185. These data provide information concerning the rate of fallout and its accumulation. During the U.S. Pacific tests in 1958, tungsten was incorporated into some devices. This was partially transformed into radioactive tungsten 185 for use as an atmospheric tracer. Although relatively small quantities of this isotope were produced, it provides information on the rate of fallout as well as a tool for studying weather

<sup>1</sup> Includes 35 steel pot and ion-exchange stations and 3 precipitation stations in the United States, 4 Coast Guard (ship) rain collecting stations in the Atlantic, and 28 steel pot and ion-exchange stations in 14 other countries.

phenomena. Recent data<sup>1</sup> indicate a decrease in the rate of fallout after generally rising rates from January to May 1959 in the United States, with the highest generally occurring during February and March on the west coast and Hawaii and in April and May on the east coast with a range between these for other areas. Analyses have not been completed through May for all stations. Monthly fallout rates in 1959 in the United States have been higher than during 1958. The few available data for June indicate a considerable decrease in the rate of fallout during June and earlier at some stations.

*Plutonium data*

Data collected over the past year by Isotopes, Inc., of Westwood, N.J., indicate that plutonium can be detected in air, soil, various human organs, and in commercially available meat products. The data are preliminary in nature and are presented only to show what data have been collected. They represent a limited sampling of the environment and, therefore, no trend can be noted. Possible future investigations may indicate the direction of any trend and would be reported at a later date. There are insufficient data to come to any conclusions concerning biological hazards from the measured levels of plutonium reported here. As the sensitivity of radiation detection equipment improves, it is reasonable to assume that other radioactive elements in weapons debris will be detected, identified, and placed in perspective within the total fallout situation.

*Human plutonium 239 analyses*

| Sample type:              | Plutonium activity, micromicrocuries per gram |
|---------------------------|-----------------------------------------------|
| Bone ash                  | Background.                                   |
| Lungs                     | 0.00536 ± 0.00049.                            |
| Tracheo-hair nodes        | 0.0292 ± 0.014.                               |
| Composite Organs—Group 1: |                                               |
| Lungs                     | 0.00784 ± 0.000077.                           |
| Pulmonary nodes           | 0.0049 ± 0.0018.                              |
| Spleen                    | 0.000518 ± 0.000095.                          |
| Kidney                    | 0.00044 ± 0.000090.                           |
| Gonad                     | 0.0035 ± 0.00086.                             |

*Animal plutonium 239 analyses*

| Same type:         | Plutonium activity, micromicrocuries per gram |
|--------------------|-----------------------------------------------|
| Beef spleen        | 0.0413 ± 0.0016.                              |
| Beef liver         | 0.00290 ± 0.00035.                            |
| Beef heart         | 0.00148 ± 0.00023.                            |
| Beef lung          | 0.00085 ± 0.00018.                            |
| Beef gonad 1       | background.                                   |
| Beef gonad 2       | 0.00059 ± 0.0008.                             |
| Stew beef 1        | 0.0300 ± 0.0014.                              |
| Stew beef 2        | 0.045 ± 0.002.                                |
| Stew beef 3        | 0.0124 ± 0.00059.                             |
| Tissue             | 0.00134 ± 0.00025.                            |
| Fluid              | 0.184 ± 0.0005.                               |
| Stew beef 4        | 0.00237 ± 0.00055.                            |
| Fluid <sup>1</sup> | 0.019 ± 0.0077.                               |
| Tissue             | 0.0018 ± 0.00026.                             |
| Chuck steak:       |                                               |
| Meat <sup>1</sup>  | 0.00019 ± 0.00014.                            |
| Bone               | 0.00066 ± 0.00036.                            |
| Fat                | background.                                   |
| Pork liver 1       | 0.00182 ± 0.00015.                            |
| Pork liver 2       | 0.00193 ± 0.00021.                            |
| Pork liver 3       | 0.00259 ± 0.00040.                            |
| Pork liver 4       | 0.00273 ± 0.00029.                            |
| Pork liver 5       | 0.00056 ± 0.00026.                            |

<sup>1</sup> Average of duplicate runs.

<sup>1</sup> HASL-69, p. 4.

## Miscellaneous plutonium 239 analyses

| Sample type:                    | Plutonium activity, micro-<br>microcuries per gram |
|---------------------------------|----------------------------------------------------|
| Swordfish I.....                | 0.0010±0.00032.                                    |
| Swordfish II.....               | 0.00034±0.00025.                                   |
| Alfalfa ash I.....              | 0.800±0.077.                                       |
| Alfalfa ash II.....             | 0.432±0.042.                                       |
| Wheat ash I <sup>1</sup> .....  | 0.127±0.023.                                       |
| Wheat ash II <sup>1</sup> ..... | 0.672±0.045.                                       |
| Rain.....                       | 0.000178±0.000027.                                 |
| Milk <sup>1</sup> .....         | 0.00016±0.00013.                                   |

<sup>1</sup> Average of duplicate runs.

## RADIOACTIVE FALLOUT

Remarks by Dr. Willard F. Libby, Commissioner, U.S. Atomic Energy Commission, for delivery before the Swiss Academy of Medical Sciences Symposium on Radioactive Fallout, Lausanne, Switzerland, March 27, 1958

## I. INTRODUCTION

The whole world is concerned over the question of radioactive fallout, particularly that from the testing of nuclear weapons. This has focused worldwide attention on the problem of the effects of radiation, whether it be from atomic fallout or medical X-rays, and a field of knowledge formerly known to only a limited group of scientists is becoming a matter of general concern, thought about and discussed by millions of people. The widespread concern may be due to the general fear of the unknown which has always been a basic human instinct. If the knowledge of the effects of radiation and the magnitude of the doses from fallout were more widely known, this would considerably allay the apprehension. So the first problem is the dissemination of the knowledge of fallout and radiation effects which has been gained over the last several years, and it is for this reason that this paper is presented. Last June the Congress of the United States held extensive hearings on radioactive fallout and radiation, and the minutes of these hearings are one of the best sources of information about the whole subject. In addition, a considerable number of articles have been published since last June which present more recent data and considerations. I hope to refer to some of these in the present paper.

Since there is every reason for the information on radioactive fallout and radiation to be known to any interested person, the U.S. Atomic Energy Commission has the policy of publishing promptly and completely on this subject, and this paper serves this function also. Before beginning a main subject of "Radioactive Fallout," I would like to mention a new development which, though related, is not entirely germane.

During the recent test operations of the U.S. Atomic Energy Commission and the U.S. Department of Defense, in Nevada, Operation Plumbob, a bomb was fired underground which had no radioactive fallout because its fireball was sealed in molten rock. The fireball consisted largely of vaporized rock which congealed and totally contained the radioactivity. Essentially no radioactivity, even that belonging to such a volatile material as radioactive krypton, escaped to any considerable degree.

The entirety of the radioactive material was found in some 700 tons of rock which had been fused and then cooled and crushed. Apparently the bomb, which had the power of 1,700 tons of ordinary chemical explosive, blew itself a bubble of vaporized rock about 55 feet in radius, which had a skin about 3 or 4 inches thick. The shock wave crushed rock out to about 130 feet so the weight of the crushed rock overhead crushed the thin eggshell when it cooled and broke it into fragments. These fragments contain the bomb debris essentially in its entirety. This means it is possible, at least in the small yield range, to contain and eliminate radioactive fallout in certain types of weapons tests. Of course, effects tests where such materials as structures and military equipment are being checked against atomic blast cannot be conducted in this manner, but these tests could conceivably be done with the special type of bomb with reduced radioactivity. Thus, it is likely that a technique has been developed which will make possible test operations which contribute much less fallout.

In addition, the nonmilitary applications of atomic explosives, which the underground shot on September 10 last year disclosed, appear to be so promising

ing that for them alone we must continue certain tests in order that these benefits may be available to the human race. For example, in the underground shot, just mentioned, we produced an earth shock which was very revealing to the seismologists in its clarity and sharpness within a considerable distance from the Nevada test site and it is certain now that from atomic detonations we will be able to determine the internal structure and character of the earth with a clarity and detail never possible with earthquake shocks because of their diffuseness in both time and location.

A second possibility is the applicability of nuclear explosions to moving earth. If the fallout hazard can be controlled. Craters produced in the Pacific Islands are convincing testimony of the possibility of making harbors in regions where the local fallout hazard is tolerable. Perhaps with the devices of reduced fallout which are now being developed such applications will be possible in more populated regions.

A third most intriguing possibility is that of shaking and breaking subterranean structures by nuclear shock. The underground detonation, despite its small 1.7 kiloton yield, is estimated to have crushed about 0.4 million tons of rock. It happened that the mountain selected consisted of rather soft rock but, nevertheless, it was consolidated and supported its own weight. After the explosion, a sphere 260 feet in radius was crushed so it could easily be mined. It was not rendered radioactive because the radioactivity was contained in thin rock shell mentioned earlier, which weighed only 700 tons and which was visually distinguishable from the ordinary rock and thus can be separated easily. It is clear that this type of application has great promise. A fourth example is the containment of the heat generated from large atomic explosions in rock structures which are dry and therefore free of the pervasive thermal conductive characteristics of steam and water. This affords a definite possibility for generating atomic power; if detonations, which are large enough to make such power economical, are practical and if the subsequent drilling and removal of the heat by injection of water to produce steam prove to be practical. A fifth example is the possibility of making radioactive isotopes by surrounding the explosive devices with appropriate materials so that the neutrons which always escape in atomic explosions can be utilized at least in part. A sixth example is the potential utilization of the radiation and heat of the bomb to cause chemical reactions. These six possible nonmilitary applications show that nuclear explosions may have peaceful applications of real importance and that the understanding of the phenomena of radioactive fallout is useful not only in conducting a weapons test, but in the promotion of important peaceful applications.

The radioactivity produced by the detonation of nuclear weapons has been extensively studied and reported upon.<sup>1-17</sup> From this work we have learned

<sup>1</sup> Hearings before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, "The Nature of Radioactive Fallout and Its Effects on Man," May 27-29, June 3-7, 1957, pts. 1 and 2, U.S. Government Printing Office, Washington, 1957.

<sup>2</sup> "Project Sunshine Bulletin No. 12," E. A. Martell, Aug. 1, 1956, AECU-3298 (Rev.).

<sup>3</sup> "The Chicago Sunshine Method," E. A. Martell, May 1956, AECU-3262.

<sup>4</sup> "Radioactive Strontium Fallout," W. F. Libby, Proc. Nat. Acad. Sci. 42, 865-890 (1956).

<sup>5</sup> "Current Research Findings on Radioactive Fallout," W. F. Libby, Proc. Nat. Acad. Sci. 42, 945-956 (1956).

<sup>6</sup> "Radioactive Fallout," W. F. Libby, Proc. Nat. Acad. Sci. 41, 758-775 (1957).

<sup>7</sup> "Doses From Natural Radioactivity and Cosmic Rays," W. F. Libby, Science 116, 57-58 (1955).

<sup>8</sup> "Radioactive Fallout in the United States," Merrill Eisenbud and J. H. Harley, Science 121, 677-680 (1955).

<sup>9</sup> "Radioactive Fallout Through September 1955," Merrill Eisenbud and J. H. Harley, Science 124, 251-255 (1956).

<sup>10</sup> "Strontium 90 in Man," J. L. Kulp, W. R. Eckelmann, and A. R. Schulert, Science 125, 219-226 (1957).

<sup>11</sup> "Strontium 90 in Man, II," J. L. Kulp, W. R. Eckelmann, A. R. Schulert, Science 127, 266-274 (1958).

<sup>12</sup> "Worldwide Travel of Atomic Debris," L. Machta, R. J. List, and L. F. Hubert, Science 124, 474-477 (1956).

<sup>13</sup> "Worldwide Effects of Atomic Weapons, Project Sunshine," August 6, 1953, R-261-AEC (amended).

<sup>14</sup> "Radiostrontium in Soil, Grass, and Bone in U.K.: 1956 Results," F. J. Bryant, A. C. Chamberlain, A. Morgan, G. S. Spicer, A. E. R. D. HP/R 2353 (1957).

<sup>15</sup> "The Hazards to Man of Nuclear and Allied Radiations," British Medical Research Council (1956).

<sup>16</sup> "A Measure of Future Strontium 90 Level From Earth Surface to Human Bone," Y. Hiyama, Gakujutsu Geppo 10, 27-43 (1957).

<sup>17</sup> "Radiological Data in Japan II," Y. Hiyama, Gakujutsu Geppo 10, 1-17 (1957).

<sup>18</sup> "The Dangers From Fallout of Strontium 90 After Atomic Bomb Explosions," E. Dahl, Teknisk Ukeblad (July 1957).

about the amount of radioactive fallout which occurs and the mechanisms for its dissemination in a broad and general way. Let us consider a few of these general points.

(1) The stratosphere plays an extremely important role for the fallout from megaton yield weapons, and the troposphere is the medium which disseminates the fallout from kiloton detonations; thus, speaking broadly, stratospheric debris is from megaton yield detonations and the tropospheric fallout is from those of lower yield. It is not that the yield of the detonation is determinative but rather that the altitude to which the fireball arises before its average density is equalized with that of the surrounding air determines the fallout rates. The megaton yield fireballs are so enormous that they stabilize at levels only above the tropopause—the imaginary boundary layer dividing the upper part of the atmosphere, the stratosphere, from the lower part, the troposphere—while the kiloton yield fireballs stabilize below the tropopause. The tropopause normally occurs at something like 40,000 to 50,000 feet altitude, although it depends on season and location. In other words, low-yield bombs fired in the stratosphere would be expected to give the same slow fallout rates as high-yield weapons do when fired in the troposphere—or on the surface if attention is focused on the part of the fallout which does not come down locally to form the oval shaped pattern pointed in the downwind direction.

(2) The stratospheric debris descends very slowly, unless, of course, it is so large as to fall in the first few hours. This paper is concerned only with the worldwide fallout—that is, the fallout which does not occur in the first few hours, and excludes the local fallout which constitutes the famous elliptical pattern which is so hazardous because of its radiation intensity, but which in test operations is carefully restricted to test areas. It is worth mentioning in passing that the local fallout may be the principal hazard in the case of nuclear war. Most serious attention should be paid to it in civilian defense programs.

The worldwide fallout from the stratosphere is literally worldwide in that the rate of descent of the tiny particles produced by the detonations is so small that something like 10 years or somewhat less probably is the average time they spend before descending to the ground, corresponding to an average annual rate of about 10 percent of the amount in the stratosphere at any given time. It is not clear as to just how they do finally descend. It seems probably that general mixing of the stratospheric air with the tropospheric air which occurs as the tropopause shifts with the season and as is brought about by the jet streams constitutes the main mechanism, and that the descent of the stratospheric fallout is never mainly due to gravity, but rather the bulk mixing of stratospheric air with tropospheric air brings the radioactive fallout particles down from the stratosphere into the troposphere where tropospheric weather finally takes over. This mechanism makes the percentage fallout rate the same for all particles too small to fall of their own weight—and the same as would be expected for gases providing some means of rapidly removing the gases from the troposphere exists, so the reverse process of the troposphere to stratosphere transfer does not confuse the issue.

(3) Worldwide radioactive fallout in the troposphere is restricted to the general latitude of the detonations for the reason that the residence time in the troposphere is about 30 days.<sup>10,11,12</sup> The life time of fine particulates in the troposphere appears to be determined by the cleansing action of the water droplets in the clouds. For those particulates which are below 1 micron in diameter, Greenfield<sup>13</sup> calculates that the mean residence time of a 1-micron particle in a typical cloud of water droplets of 20 microns diameter may vary between 50 and 300 hours, but that a particle of 0.04 micron diameter will last only 30 to 60 hours, and that a particle of 0.01 micron diameter will last only 15 to 20 hours. The theory calculates the diffusion due to Brownian motion and says that it is just this motion induced by the collisions with the air molecules which makes possible the contact between the fallout particles and the cloud drops. Since this theory is based on first principles with the single assumption that the fall-

out particle sticks to the water droplet on impact—an assumption so plausible as to be almost beyond doubt—it is no surprise to learn experimentally that the Greenfield theory appears to be correct.

There is essentially no worldwide fallout in the absence of rainfall; i.e., in desert regions—except for a little that sticks to tree leaves, blades of grass, and general surfaces, by the same type of mechanism Greenfield describes in the case of clouds. Thus we see that it is the moisture in the troposphere which assures the short lifetime of the worldwide fallout particles, and that when the stratospheric air which contains essentially no moisture and therefore has no cleansing mechanism descends into the troposphere, the tropospheric moisture proceeds to clean it up. On this model, we see that for submicron fallout particles, weather phenomena are controlling, and that the bombs which have insufficient energy to push their fireballs above the troposphere will have their worldwide fallout brought down in raindrops in a matter of about a month, in extreme contrast with the stratospheric material which apparently stays aloft for something like 10 years on the average. The contrast between these two lifetimes means that the concentration of radioactive fallout in the stratospheric air in terms of equal densities of air is always much higher in tropospheric air. This has been experimentally observed to be true.<sup>14</sup> In fact, the stratospheric content is about 100-fold higher than that of the troposphere corresponding to the much longer stratospheric residence time. Later in this paper new data on the fallout content of the stratosphere are given.

It is inherent in the Greenfield mechanism that the total worldwide fallout will be proportional to rainfall if other factors are not allowed to vary. Thus we find that the Mediterranean basin<sup>15</sup> affords a good example of the truth of this principle. Other regions are the Northeastern United States, the Southeastern United States, the Northwest United States and the Southwest United States.<sup>16</sup> It is now well established that desert areas have very little fallout.

(4) After falling to the ground in the form of rain or being picked up on the surface of the leaves of grass or trees by the same type of Brownian motion accretion mechanism causing cloud drop pickup, the radioactive fallout may enter the biosphere by normal biological processes. Radioactive strontium 90 and radioactive cesium 137 are the two principal isotopes which have this facility and are produced in high yield by the fission reaction and are of long enough lifetimes to be disseminated worldwide particularly by the stratospheric mechanism—about 28 years' half life for each. Strontium 90 is produced at a level equivalent to about 1 millicurie of strontium 90 per square mile of the earth's surface for every 2 megatons of fission energy, and radiocesium is produced at about 50 percent higher yield. Of the two isotopes, strontium 90, because of its chemical similarity to calcium, collects in human bone, where it is held for years and where its radiations might then cause deleterious effects to the health of the individual, such as leukemia or bone cancer. It is interesting that strontium 90 constitutes a relatively less important genetic hazard because of the short range of its radioactive radiation and the fact that it is not held in the reproductive organs. Radiocesium stays in the human body only 6 or 8 months on the average, because it has no permanent structure like the bone for which it has a natural affinity. As a result, the amount of radiation occurring from internally ingested radiocesium is much less, and most likely is subject to palliative measures calculated to reduce its time in the body. Strontium 90 taken into the bone, however, appears to be stored for many years, the exact time not being known very well.<sup>17</sup>

Radiostrontium is taken into the body because of its similarity to calcium, but there is a definite difference in chemical behavior which causes animal organisms to prefer calcium. Thus the radiostrontium content of newly deposited bone calcium is less than that for food calcium. In many countries, the principal source of calcium is milk products, so the fact that cow's milk has only one-seventh the strontium in it per gram of calcium that the cow's food has, and that milk taken into the human body similarly deposits calcium in the bones with

<sup>10</sup> "The Radiological Dose to Persons in the U.K. Due to Debris from Nuclear Test Explosions Prior to January 1956," N. G. Stewart, R. N. Crooks, and E. M. R. Fisher, A.E.R.E. HP/R 2017 (1956).

<sup>11</sup> "Selbstreinigung der Atmosphäre," O. Hazen and G. Schumann, Z. Physik 142, 128-132 (1955).

<sup>12</sup> "Rain Scavenging of Radioactive Particulate Matter From the Atmosphere," S. M. Greenfield, Journal of Meteorology 14, 115-25 (1957).

<sup>13</sup> "Natural Distribution of Cosmic Ray Produced Tritium II," Hans von Buttlar, W. F. Libby, J. Inorg. & Nuc. Chem. 1, 75 (1955).

<sup>14</sup> "The Radiological Dose to Persons in the U.K. Due to Debris from Nuclear Test Explosions," A.E.R.E. HP/R 1701, N. G. Stewart, R. N. Crooks, and E. M. R. Fisher (1955).

<sup>15</sup> NYO-4885, "A Study of Fallout in Rainfall Collections From March Through July 1956," W. R. Collins and N. A. Hallden, Apr. 30, 1957. NYO-4751, "Summary of Analytical Results From the HASL Strontium Program to June 1956," J. H. Harley, E. P. Hardy, Jr., G. A. Wolford, I. B. Whitney, M. Eisenbud, Aug. 31, 1956. NYO-4862, "Summary of Analytical Results from the HASL Strontium Program, July Through December 1956," J. H. Harley, E. P. Hardy, Jr., I. B. Whitney, and M. Eisenbud.

<sup>16</sup> "Chemical Dynamics of Bone Mineral," W. F. and Margaret W. Neuman, Monograph, University of Chicago Press (1958).

only half the strontium 90 content of the milk itself means that human beings naturally have a lower strontium 90 to calcium ratio for new bone than for the food source by something like a factor of 15 for dairy products. On the other hand, vegetation containing strontium 90 also deposits its strontium relatively inefficiently with a factor of something like 4 less strontium in the bone from these sources than is carried in the vegetable food itself—all relative to calcium. In some countries where calcium in the human diet comes principally from vegetables other sources of calcium contribute, some of which contain essentially no strontium 90—namely seafood. Because fallout is diluted so quickly by the action of the waves in the ocean, the concentration of the radioactive strontium in the sea calcium is very much lower than it is in the soil of the land in which the grass and vegetable crops grow. This difference becomes even larger when the effects of direct leaf and stem base pickup are considered. This perhaps accounts for the high values reported by Ogawa<sup>2</sup> for rice in Japan. So, fish from the sea are naturally at the lowest level in radiostrontium and seafood should be the lowest source of calcium among ordinary human foods. With all of these factors taken together, the world populations assimilate calcium at a much lower radiostrontium content than is exhibited by land plants to a very considerable degree. Eckelmann, Kuip, and Schuler<sup>3</sup> have given a detailed sample calculation recently, based on their extensive measurements on human bone.

(5) The biological hazard from the radioactive fallout from weapons testing is not well known, and like many biological problems the determination of the hazard in any exact way seems to be almost impossibly difficult. Fortunately, however, it is possible to compare the radiation from radioactive fallout with the intensities of natural radiation to which we are always exposed. For example, it is clear that the present level of the radiostrontium in the bones of young children which are, of course, closest to being in equilibrium with the fallout since adults have had their bones some time even before there was any radioactive fallout, is about 2 milliroentgens per year as compared to an average natural dosage of 150 to 200 milliroentgens per year, about 1 to 2 percent of the dosage from natural sources to the bones depending upon location. Natural radioactivity present in the ground, building materials, and even in our own bodies gives us an average total dose at sea level of about 150 milliroentgens per year, and medical X-rays add something like another 150 milliroentgens. The radiocesium taken into the body and the penetrating radiations from nonassimilable radioactive fallout contribute perhaps another 8 or 4 percent to the whole body dosage. Thus the total dosage to freshly formed human bone is at most 5 percent of the natural dosage. Furthermore, we do know that the variations in natural background dosages from place to place are enormous in magnitude as compared to the average value, and of course as compared to the fallout dosage. For example, it has been found<sup>4</sup> that exposure rate from external radiation rise from a value of about 110 milliroentgens per year at sea level to something like 230 milliroentgens per year at 5,000 to 6,000 feet altitude in the United States. These numbers are considerably larger than those expected on the basis of earlier calculations and measurements,<sup>5</sup> the increase apparently being due to the cosmic rays and their increase with altitudes.<sup>6</sup> In addition, the effects of radioactivity in the soil and in building

<sup>2</sup> "Fallout and Rice Contamination in Japan," I. Ogawa, Bulletin of the Atomic Scientists 14, 35 (1958).

<sup>3</sup> "External Radiation Measurements in the United States," L. P. Solon, W. M. Lowder, A. V. Zila, H. D. LeVine, H. Blatz, and M. Eisenbud, Science (in press).

<sup>4</sup> P. R. J. Burch, Physical Society, Series A 57, 421 (1954).

<sup>5</sup> "Gamma Rays From Local Radioactive Sources," H. V. Neher, Science 115, 8257 (1957).

<sup>6</sup> "The Biological Effects of Atomic Radiation," National Academy of Sciences, (1956).

materials made of stone or soil are considerable, amounting in some instances to 50 or 100 percent of the average natural background dose at sea level, and the magnitude of the medical exposures to X-rays approximates on the average those due to all natural sources.<sup>7</sup>

We see, therefore, that whatever the extent of our ignorance of the biological effects of radiation, we do know that these effects are not unexperienced by the human species, even from the genetic point of view, since it is clear now that persons living at high altitudes on granitic rocks always have received extra radiation many times greater than is contained in the radioactive fallout from the testing of nuclear weapons, and that even those living on certain sedimentary rocks at sea level always have received about 10 to 20 times the present fallout dose.

Of course, this does not mean that any of the effects from radioactive fallout are in any way negligible and it does not mean that certain numbers of people will not be injured by radioactive fallout radiations, even though these numbers be very small relative to the total population of the world. However, the problem is bounded, and commonsense and good judgment can be brought to bear on the extent of the biological hazards even though they are not now known exactly, and probably will not be well understood for many years. Researches to increase this understanding are being done, especially in the United States and United Kingdom and other countries. Information on radioactive fallout and all of its aspects, both physical and biological, is collected and collated by the United Nations' Scientific Committee on the Effects of Atomic Radiation, which is drafting its first report at the present time.

(6) From our study of radioactive fallout from testing, we have learned much of value about the circulation of the atmosphere of the world, and we have much more to learn as the study continues, particularly in the stratosphere by balloon and aircraft sampling techniques being carried out principally in the United States at the present time. As we undertake the problem of locating the fallout in the oceans, we undoubtedly will learn much of interest to oceanographers about the circulation of the water in the seas.

(7) From our understanding of radioactive fallout from tests, we are the better able to devise methods of civilian defense against fallout in the case of nuclear war, and widespread popular interest in the potential possible hazards from radioactive fallout from nuclear tests has led to a considerable understanding on the part of the general public of these strange phenomena. From this debate and study may come the protection for millions in the case nuclear war should occur.

Understanding of the nature of the mechanism by which radioactive fallout is disseminated has led to the reduction of the offsite fallout from testing. We know now that bombs placed upon the ground produce relatively more local fallout and therefore less worldwide fallout. It seems likely that firing on the surface of the sea has a similar, though probably considerably less marked effect.

## II. RECENT DATA AND THEIR IMPLICATIONS

Figures 1, 2, 3, 4, and 5 (attached) and tables I, II, and III, which are up-to-date versions of earlier publications, give the most recent results for the fallout observed for rainfall collections, for the strontium 90 content of milk (fresh and dry), for human bone, and for animal bone. It is particularly interesting to note that the data continue to show the principal features noted previously and that little new in principle has appeared.

<sup>7</sup> "Aspects of Genetic and Somatic Risk in Diagnostic Roentgenology," B. P. Sonnenblick, Journal of Newark Beth Israel Hospital, Newark, N.J., VII, 2, 81 (1957).

TABLE I.—Health and safety laboratory pasture program

| Location            | Strontium 90 in hay |                 |                |                     | Strontium 90 in bone |                |                     |
|---------------------|---------------------|-----------------|----------------|---------------------|----------------------|----------------|---------------------|
|                     | Site                | Sampling date   | Percent Ca ash | $\mu\text{Ci/g Ca}$ | Animal               | Sampling date  | $\mu\text{Ci/g Ca}$ |
| Tifton, Ga.         | Unimproved.         | September 1954. | 3.8            | 30 $\pm$ 2          | Calves               | Fall, 1953     | 3.8                 |
|                     | Improved.           | do              | 5.2            | 3.9 $\pm$ 0.6       | do                   | September 1954 | 7.0 $\pm$ 0.3       |
|                     | do                  | June 1955       | 7.5            | 34 $\pm$ 2          | do                   | do             | 2.7 $\pm$ 0.2       |
|                     | do                  | September 1955  | 6.9            | 21 $\pm$ 1          | do                   | October 1955   | 12 $\pm$ 0.3        |
|                     | do                  | May 1956        | 5.6            | 89.9 $\pm$ 2.3      | do                   | Oct. 24, 1956  | 18.45 $\pm$ 0.47    |
|                     | do                  | do              | do             | 90.8 $\pm$ 2.3      | do                   | do             | 18.36 $\pm$ 0.44    |
| New Brunswick, N.J. | do                  | September 1955  | 5.8            | 109.9 $\pm$ 1.7     | do                   | do             | 9.93 $\pm$ 0.35     |
|                     | do                  | Sept. 19, 1954  | 5.0            | 120.5 $\pm$ 2.7     | do                   | do             | 9.53 $\pm$ 0.34     |
|                     | do                  | July 4, 1955    | 7.1            | 9.1 $\pm$ 0.4       | Sheep                | Fall, 1953     | 1.1                 |
|                     | do                  | October 1955    | 6.9            | 85 $\pm$ 2          | do                   | Sept. 8, 1954  | 2.7 $\pm$ 0.2       |
|                     | do                  | July 3, 1956    | 6.3            | 77 $\pm$ 2          | do                   | Oct. 14, 1955  | 4.1 $\pm$ 0.2       |
|                     | do                  | Oct. 13, 1956   | 9.0            | 88.8 $\pm$ 2.1      | do                   | Oct. 11, 1956  | 3.83 $\pm$ 0.08     |
| Raleigh, N.C.       | do                  | Sept. 16, 1954  | 8.4            | 86.9 $\pm$ 2.1      | do                   | do             | 5.5 $\pm$ 0.3       |
|                     | do                  | Sept. 1, 1955   | 3.5            | 55.0 $\pm$ 1.4      | do                   | do             | 7.5 $\pm$ 0.3       |
|                     | Pig pasture         | July 20, 1955   | 12.5           | 26 $\pm$ 0.5        | do                   | September 1954 | 2.1 $\pm$ 0.2       |
|                     | do                  | Aug. 4, 1956    | 10.3           | 60 $\pm$ 3          | do                   | Dec. 14, 1955  | 8.6 $\pm$ 0.4       |
|                     | do                  | do              | do             | 38.6 $\pm$ 0.3      | do                   | Sept. 19, 1956 | 26.2 $\pm$ 0.1      |
|                     | do                  | do              | do             | 24.8 $\pm$ 0.3      | Fig.                 | Sept. 24, 1956 | 1.87 $\pm$ 0.08     |
| Ithaca, N.Y.        | do                  | Sept. 10, 1954  | 33             | 1.15 $\pm$ 0.07     | do                   | do             | 1.61 $\pm$ 0.04     |
|                     | do                  | June 15, 1955   | 13             | 19 $\pm$ 0.6        | Sheep                | Fall, 1953     | 1.1                 |
|                     | do                  | Sept. 14, 1955  | 12             | 20 $\pm$ 1          | do                   | Sept. 20, 1954 | 2.6 $\pm$ 0.2       |
|                     | do                  | June 7, 1956    | 9.1            | 28.15 $\pm$ 0.24    | do                   | Sept. 20, 1955 | 5.4 $\pm$ 0.3       |
|                     | do                  | Aug. 25, 1956   | 10.3           | 15.06 $\pm$ 0.27    | Lamb                 | Oct. 20, 1956  | 8.8 $\pm$ 0.4       |
|                     | do                  | do              | do             | do                  | do                   | do             | 7.8 $\pm$ 0.3       |
| Logan, Utah         | Robinson Farm       | Sept. 18, 1954  | 7.0            | 10 $\pm$ 0.6        | do                   | do             | 10.6 $\pm$ 0.4      |
|                     | College Farm        | do              | 8.2            | 6.3 $\pm$ 0.7       | Hog                  | do             | 2.69 $\pm$ 0.10     |
|                     | do                  | July 18, 1955   | 7.6            | 19 $\pm$ 1          | do                   | do             | 2.18 $\pm$ 0.10     |
|                     | do                  | June 10, 1956   | 16.2           | 8.27 $\pm$ 0.80     | do                   | do             | 2.56 $\pm$ 0.12     |
|                     | do                  | do              | do             | 7.89 $\pm$ 0.53     | Sheep                | Fall, 1953     | 1.2                 |
|                     | do                  | do              | do             | do                  | do                   | do             | 0.6                 |
| Mandan, N. Dak.     | do                  | do              | do             | do                  | do                   | September 1954 | 4.4 $\pm$ 0.2       |
|                     | do                  | do              | do             | do                  | do                   | do             | 1.7 $\pm$ 0.2       |
|                     | do                  | do              | do             | do                  | do                   | October 1955   | 8.2 $\pm$ 0.4       |
|                     | do                  | do              | do             | do                  | do                   | May 1956       | 6.4 $\pm$ 0.4       |
|                     | do                  | do              | do             | do                  | do                   | Nov. 13, 1956  | 5.10 $\pm$ 0.05     |
|                     | do                  | do              | do             | do                  | do                   | Mar. 27, 1956  | 5.5 $\pm$ 0.3       |
|                     | do                  | do              | do             | do                  | do                   | do             | 23 $\pm$ 0.6        |
|                     | do                  | do              | do             | do                  | do                   | do             | 24 $\pm$ 0.6        |
|                     | do                  | do              | do             | do                  | do                   | do             | 23 $\pm$ 0.6        |
|                     | do                  | do              | do             | do                  | do                   | do             | 24 $\pm$ 0.6        |

TABLE II  
SP in fallout at monitoring sites outside continental United States (high-tailed statistics steel pot collections)

| Month                                     | Precipitation<br>in inches | Observed due<br>E <sub>0</sub> /μg/g | Mc Sr <sup>90</sup> /μg<br>calculated<br>from theory |
|-------------------------------------------|----------------------------|--------------------------------------|------------------------------------------------------|
| Bangkok, Thailand (14° N.):               |                            |                                      |                                                      |
| March 1957                                | 1.96                       | 0.08                                 | 0.086                                                |
| April 1957                                | 5.85                       | 0.18                                 | 0.25                                                 |
| May 1957                                  | 1.56                       | 0.07                                 | 0.08                                                 |
| June 1957                                 | 9.36                       | 0.16                                 | 0.41                                                 |
| July 1957                                 | 6.63                       | 0.22                                 | 0.29                                                 |
| August 1957                               | 11.70                      | 0.39                                 | 0.51                                                 |
| Nagasaki, Japan (35° N.):                 |                            |                                      |                                                      |
| August 1956                               | 17.43                      | 0.34                                 | 0.76                                                 |
| September 1956                            | 16.1                       | 0.17                                 | 0.21                                                 |
| October 1956                              | 3.59                       | 0.06                                 | 0.16                                                 |
| November 1956                             | 1.44                       | 0.06                                 | 0.03                                                 |
| December 1956                             | 1.37                       | 0.22                                 | 0.09                                                 |
| January 1957                              | 3.94                       | 1.01                                 | 1.72                                                 |
| February 1957                             | 3.28                       | 1.17                                 | 1.43                                                 |
| March 1957                                | 1.40                       | 0.36                                 | 0.61                                                 |
| April 1957                                | 11.27                      | 1.96                                 | 2.4                                                  |
| May 1957                                  | 4.44                       | 1.72                                 | 1.3                                                  |
| June 1957                                 | 10.18                      | 2.7                                  | 4.0                                                  |
| July 1957                                 | 29.47                      | 1.07                                 | 2.1                                                  |
| August 1957                               | 11.36                      | 1.67                                 | 2.1                                                  |
| September 1957                            | 14.74                      | 1.46                                 | 2.1                                                  |
| Himeji, Japan (35° N.):                   |                            |                                      |                                                      |
| August 1956                               | 11.03                      | 0.30                                 | 0.52                                                 |
| September 1956                            | 9.63                       | 0.27                                 | 0.19                                                 |
| October 1956                              | 3.01                       | 0.11                                 | 0.12                                                 |
| November 1956                             | 1.04                       | 0.06                                 | 0.07                                                 |
| December 1956                             | 2.23                       | 0.29                                 | 0.07                                                 |
| January 1957                              | 2.19                       | 0.08                                 | 0.08                                                 |
| February 1957                             | 2.26                       | 0.25                                 | 0.06                                                 |
| March 1957                                | 11.00                      | 1.12                                 | 2.3                                                  |
| April 1957                                | 6.44                       | 0.67                                 | 1.35                                                 |
| May 1957                                  | 10.22                      | 0.83                                 | 2.2                                                  |
| June 1957                                 | 21.10                      | 0.17                                 | 4.4                                                  |
| July 1957                                 | 4.49                       | 0.47                                 | 4.4                                                  |
| August 1957                               | 10.92                      | 2.77                                 | 2.3                                                  |
| Rio de Janeiro, Brazil (23° S.):          |                            |                                      |                                                      |
| September 1956                            | 1.96                       | 0.12                                 | 0.05                                                 |
| October 1956                              | 3.12                       | 0.21                                 | 0.13                                                 |
| November 1956                             | 3.51                       | 0.06                                 | 0.13                                                 |
| December 1956                             | 2.51                       | 0.02                                 | 0.15                                                 |
| January 1957                              | 2.73                       | 0.04                                 | 0.12                                                 |
| February 1957                             | 6.07                       | 0.05                                 | 0.22                                                 |
| Salisbury, South Rhodesia (30° S.):       |                            |                                      |                                                      |
| September 1956                            | 7.41                       | 0.18                                 | 0.27                                                 |
| October 1956                              | 7.90                       | 0.12                                 | 0.34                                                 |
| November 1956                             | 6.55                       | 0.09                                 | 0.26                                                 |
| December 1956                             | 8.97                       | 0.04                                 | 0.04                                                 |
| January 1957                              | 5.46                       | 0.04                                 | 0.24                                                 |
| February 1957                             | 1.17                       | 0.04                                 | 0.06                                                 |
| Kilimanjaro, Kenya (0°):                  |                            |                                      |                                                      |
| January 1957                              | 8.76                       | 0.14                                 | 0.43                                                 |
| February 1957                             | 2.34                       | 0.26                                 | 0.10                                                 |
| March 1957                                | 3.12                       | 0.03                                 | 0.13                                                 |
| April 1957                                | 7.02                       | 0.31                                 | 0.31                                                 |
| May 1957                                  | 14.83                      | 0.64                                 | 0.64                                                 |
| June 1957                                 | 1.08                       | 0.089                                | 0.089                                                |
| July 1957                                 | 1.46                       | 0.166                                | 0.084                                                |
| August 1957                               | 2.20                       | 0.087                                | 0.087                                                |
| September 1957                            | 2.34                       | 0.088                                | 0.10                                                 |
| Dakar, French West Africa (14° N.):       |                            |                                      |                                                      |
| August 1957                               | 6.2                        | 0.52                                 | 0.28                                                 |
| September 1957                            | 10.44                      | 0.24                                 | 0.45                                                 |
| Durban, Union of South Africa (30° S.):   |                            |                                      |                                                      |
| June 1957                                 | 30                         | 0.80                                 | 0.17                                                 |
| July 1957                                 | 39                         | 0.17                                 | 0.06                                                 |
| August 1957                               | 78                         | 0.66                                 | 0.34                                                 |
| September 1957                            | 4.74                       | 0.230                                | 0.21                                                 |
| October 1957                              | 4.26                       | 0.501                                | 0.187                                                |
| November 1957                             | 1.66                       | 0.074                                | 0.084                                                |
| Vienna, Austria (47° N.):                 |                            |                                      |                                                      |
| June 1957                                 | 78                         | 0.45                                 | 0.29                                                 |
| July 1957                                 | 5.07                       | 1.86                                 | 1.86                                                 |
| August 1957                               | 2.73                       | 1.07                                 | 1.0                                                  |
| September 1957                            | 3.51                       | 1.17                                 | 1.3                                                  |
| Klagenfurt, Austria (47° N.): August 1957 |                            |                                      |                                                      |

| Month                  | Precipitation in inches | Observed $\text{mc Sr}^{90}/\text{mi}^3$ |                 | Precipitation in inches | Observed $\text{mc Sr}^{90}/\text{mi}^3$ University of Hawaii | $\text{Mc Sr}^{90}/\text{mi}^3$ calculated from theory |
|------------------------|-------------------------|------------------------------------------|-----------------|-------------------------|---------------------------------------------------------------|--------------------------------------------------------|
|                        |                         | AEC Lab                                  | Weather station |                         |                                                               |                                                        |
| Oahu, Hawaii (20° N.): |                         |                                          |                 |                         |                                                               |                                                        |
| June 1957              | 0.32                    | 0.72                                     |                 | 0.83                    | 0.58                                                          | 0.036                                                  |
| July 1957              | 2.10                    | 1.36                                     | 0.477           | 1.82                    | .42                                                           | .071                                                   |
| August 1957            | 1.57                    | .303                                     | .156            | 3.08                    | .306                                                          | .124                                                   |
| September 1957         | 1.54                    | .274                                     | .188            | .62                     | .169                                                          | .027                                                   |

*Sr<sup>90</sup> in fallout at other U.S. monitoring sites (high-walled stainless steel pot collections)*

| Month                          | Precipitation<br>in inches | Observed<br>mc Sr <sup>90</sup> /mi <sup>3</sup> | Mc Sr <sup>90</sup> /mi <sup>3</sup> calculated<br>from theory |                                 |
|--------------------------------|----------------------------|--------------------------------------------------|----------------------------------------------------------------|---------------------------------|
|                                |                            |                                                  | With<br>Russian<br>component                                   | Without<br>Russian<br>component |
| Lemont, Ill. (44° N.):         |                            |                                                  |                                                                |                                 |
| December 1956                  | 1.26                       | 0.14                                             | 0.51                                                           | 0.053                           |
| January 1957                   | 2.06                       | .30                                              | .38                                                            | .068                            |
| February 1957                  | 1.77                       | .27                                              | .72                                                            | .076                            |
| March 1957                     | 1.08                       | .47                                              | .80                                                            | .085                            |
| April 1957                     | 0.09                       | 1.15                                             | 2.5                                                            | 1.3                             |
| May 1957                       | 3.21                       | .77                                              | 1.5                                                            | .68                             |
| June 1957                      | 5.94                       | .48                                              | 1.95                                                           | 1.0                             |
| July 1957                      | 5.98                       | 1.57                                             | 3.6                                                            | 1.9                             |
| August 1957                    | 6.36                       | .69                                              | 2.1                                                            | 1.1                             |
| September 1957                 | 1.08                       | .12                                              | .41                                                            | .21                             |
| Birmingham, Ala. (33° N.):     |                            |                                                  |                                                                |                                 |
| April 1957                     | 5.41                       | .83                                              | 1.1                                                            | .23                             |
| May 1957                       | 2.96                       | .39                                              | .62                                                            | .13                             |
| June 1957                      | 7.70                       | .95                                              | 1.6                                                            | .33                             |
| July 1957                      | 2.62                       | .60                                              | .55                                                            | .11                             |
| August 1957                    | 4.19                       | 1.10                                             | .87                                                            | .37                             |
| September 1957                 | 9.59                       | .42                                              | 2.0                                                            | .41                             |
| Salt Lake City, Utah (38° N.): |                            |                                                  |                                                                |                                 |
| December 1956                  | 1.57                       | .31                                              | .66                                                            | .071                            |
| January 1957                   | 1.37                       | .8                                               | .64                                                            | .068                            |
| February 1957                  | .72                        | .83                                              | .29                                                            | .031                            |
| March 1957                     | 2.18                       | 2.39                                             | .87                                                            | .093                            |
| April 1957                     | 8.24                       | 2.30                                             | 1.4                                                            | .55                             |
| May 1957                       | 3.37                       | .81                                              | 1.5                                                            | .70                             |
| June 1957                      | 1.47                       | 1.61                                             | .66                                                            | .31                             |
| July 1957                      | .31                        | .94                                              | .13                                                            | .06                             |

| Month                              | Precipitation in inches | Observed mc Sr <sup>90</sup> /mi <sup>3</sup> | Mc Sr <sup>90</sup> /mi <sup>3</sup> calculated from theory |
|------------------------------------|-------------------------|-----------------------------------------------|-------------------------------------------------------------|
| West Los Angeles, Calif. (34° N.): |                         |                                               |                                                             |
| December 1956                      | 0.49                    | 0.15                                          | 0.02                                                        |
| January 1957                       | 3.88                    | .90                                           | .16                                                         |
| February 1957                      | 1.94                    | .76                                           | .08                                                         |
| March 1957                         | .96                     | .09                                           | .041                                                        |
| April 1957                         | 1.33                    | .84                                           | .28                                                         |
| May 1957                           | .27                     | .24                                           | .068                                                        |
| June 1957                          | .06                     | .12                                           | .012                                                        |
| July 1957                          | .03                     | .92                                           | .006                                                        |

Some local fallout from Nevada.

| Month                        | Precipitation in inches | Observed mc Sr <sup>90</sup> /mi <sup>3</sup> | Mc Sr <sup>90</sup> /mi <sup>3</sup> calculated from theory |                        |
|------------------------------|-------------------------|-----------------------------------------------|-------------------------------------------------------------|------------------------|
|                              |                         |                                               | With U.S. component                                         | Without U.S. component |
| South Miami, Fla., (26° N.): |                         |                                               |                                                             |                        |
| April 1957                   | 5.04                    | 0.53                                          | 1.07                                                        | 0.22                   |
| May 1957                     | 10.11                   | .50                                           | 2.10                                                        | .44                    |
| June 1957                    | 5.82                    | .68                                           | 1.28                                                        | .27                    |
| July 1957                    | 8.5                     | 1.51                                          | 1.7                                                         | .35                    |
| August 1957                  | 13.6                    | .75                                           | 2.8                                                         | .68                    |
| September 1957               | 6.27                    | .52                                           | 1.3                                                         | .27                    |



TABLE III.—Average strontium 90 content in man, July 1, 1956–June 30, 1957

(Values are in  $\mu\text{mc Sr/g}$  of Ca, normalized to the whole skeleton)

(Figures in parentheses give the number of samples in the category)

| Location           | Age at death (year) |           |           |           |           |           |           |           | 20 to 80 (average) |
|--------------------|---------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--------------------|
|                    | 0 to 4              | 5 to 9    | 10 to 19  | 20 to 29  | 30 to 39  | 40 to 49  | 50 to 59  | 60 to 80  |                    |
| North America..... | 0.67 (30)           | 0.60 (17) | 0.58 (15) | 0.07 (14) | 0.06 (9)  | 0.08 (16) | 0.05 (5)  | 0.07 (18) | 0.070 (62)         |
| South America..... | .16 (3)             | .20 (1)   | .19 (3)   | .09 (3)   | .02 (2)   | .02 (2)   | .06 (3)   | .01 (1)   | .054 (13)          |
| Europe.....        | .65 (2)             | .34 (6)   | .34 (6)   | .03 (20)  | .07 (4)   | .04 (6)   | .06 (1)   | .06 (2)   | .054 (23)          |
| Africa.....        | .93 (1)             | .12 (2)   | .04 (2)   | .03 (2)   | .05 (3)   | .04 (4)   | .06 (3)   | .05 (5)   | .035 (9)           |
| Asia.....          | .73 (3)             | .60 (2)   | .32 (2)   | .06 (3)   | .04 (3)   | .12 (3)   | .03 (3)   | .03 (3)   | .070 (32)          |
| Australasia.....   | .64 (39)            | .57 (26)  | .30 (13)  | .059 (49) | .047 (27) | .03 (4)   | .052 (17) | .065 (26) | .080 (10)          |
| Entire world.....  |                     |           |           |           |           |           |           |           | .060 (106)         |

Figure 8 shows preliminary data on the stratospheric content of strontium 90. The data are preliminary for the reason that the air filter efficiencies are unknown at the present, although estimated to be something like 25 percent. The samples are taken by pumping stratospheric air through filters which are then analyzed. It is clear that even though an enormous scatter is present for reasons of time and experiment, it also is clear that there is no large variation in the stratospheric content of strontium 90 between the latitude of  $30^{\circ}$  S. and the Northern Hemisphere. Since most of the megaton yield explosions have occurred in the northern latitudes, though the Pacific testing grounds are only  $11^{\circ}$  north of the equator, it appears that this evidence argues for rapid north and south mixing in the stratosphere. As we shall see later, other evidence in the dissemination of nonradioactive carbon dioxide derived from the combustion of fossil fuels<sup>1</sup> and of the dissemination of bomb-derived radioactive carbon-14 seems to confirm this.<sup>2</sup> It is interesting to note also that the actual content of the stratosphere is not in disagreement with the estimates given earlier,<sup>3</sup> although the value of the filter efficiencies remains to be settled, and it is estimated at the efficiency of about 25 percent on evidence assuming homogeneity of the particle size. Experiments are now underway to settle the point.

In the model previously advanced,<sup>4</sup> it is proposed that material introduced into the stratosphere is mixed immediately horizontally to a uniform concentration and has a residence time of 10 years. Further, it is assumed that the latitudinal spread of tropospheric bomb clouds is only  $10^{\circ}$  with a sharp-step function rather than a normal error curve distribution. The bomb debris is arbitrarily assigned to the stratosphere except for 1 percent tropospheric in the case of megaton yields. Local fallout is assumed to be 80 percent for land-surface shots, 20 percent for surface-water shots, and 10 percent for air shots. All kilo-yield shots are assigned to the troposphere. On these very simple bases we are then, from classified data about the magnitudes and nature of the explosions, able to estimate the total fallout for any place on earth if the deposition from the troposphere is assumed to be proportional to the rain content at a given location. Figure 7 gives such a theoretical latitudinal fallout profile for worldwide fallout as of December 1957, neglecting rainfall variation, and figure 8 is the corresponding world map. Figure 9 gives the corresponding timewise variations in the northern latitudes and compares them with the rainfall fallout curves for Milford Haven in England.<sup>5</sup> Figure 10 gives a similar comparison for Chicago and Pittsburgh. Curves for other latitudes are given in figures 11 and 12. Figure 13 gives the estimated stratospheric reservoir and the expected composition in strontium 89 versus time. If a further assumption is made; namely, that the proportion of the fallout in a given location is given by the ratio of the rainfall to the worldwide average, 0.77 meters,<sup>6</sup> it is possible to compare the detailed fallout observed by the pot collection programs in various localities with the theoretical predicted values, and these are given in table II.

On the basis of these comparisons and in the absence of conclusive evidence as to the age of radioactive fallout, it appears that the simple theory outlined explains the known information within the experimental error. It may develop when more reliable data are available on the age of fallout through the use of short-lived, 12.8-day half-life barium 140 fission product, that a mechanism by which a sort of concentrated leaking from the stratosphere occurs at a latitude of about  $40^{\circ}$  more may be proved or disproved. At the present time the ob-

<sup>1</sup> "Reduction of Atmospheric Radiocarbon Concentration by Fossil Fuel Carbon Dioxide and the Mean Life of Carbon Dioxide in the Atmosphere," G. J. Fergusson, Proc. Royal Soc. of London, series A 243, 561-74 (1958).

<sup>2</sup> "Radiocarbon Concentration in Modern Wood," H. E. Suess, Science 122, 415 (1955).

<sup>3</sup> "Natural Distribution of Radiocarbon and the Exchange Time of  $\text{CO}_2$  between Atmosphere and Sea," H. Craig, Tellus 9, 1 (1957).

<sup>4</sup> "Carbon Dioxide Exchange Between Atmosphere and Ocean, and the Question of an Increase of Atmospheric  $\text{CO}_2$  During the Past Decades," R. Revelle and H. E. Suess, Tellus 9, 18 (1957).

<sup>5</sup> "The Distribution of Carbon-14 in Nature," J. R. Arnold and E. C. Anderson, Tellus 9, 28 (1957).

<sup>6</sup> "Atom Bomb Effect—Recent Increase of Carbon-14 Content of the Atmosphere and Biosphere," T. A. Rafter and G. J. Fergusson, Science 126, 557 (1957).

<sup>7</sup> T. A. Rafter, New Zealand Journal on Science and Technology B37, 20 (1955); 18, 871 (1957).

<sup>8</sup> M. Williams, private communication.

<sup>9</sup> "The Worldwide Deposition of Long-Lived Fission Products From Nuclear Test Explosions," A.E.R.E. HP/R 2354, N. G. Stewart, R. G. D. Osmond, R. N. Crooks, W. M. R. Fisher (1957).

<sup>10</sup> "Geochemistry," Rankama and Sahama, University of Chicago Press (1950).

served extreme concentration may be explained as being due to coincidence of the tropospheric fallout from the United States and Russian tests. If this theory be correct, the barium 140 content in periods of high fallout will show that the fallout is young. It is to be hoped that these data will be forthcoming soon.

Machta,<sup>14</sup> and Stewart, Osmond, Crooks, and Fisher<sup>15</sup> have stated that meteorological considerations and likely stratospheric wind patterns, together with evidence that the  $\text{Sr}^{90}/\text{Sr}^{90}$  ratio of the fallout shows the fallout to be old, have led them to the conclusion that the heavier fallout observed in the 40° to 50° N. latitude band is stratospheric and not tropospheric in origin as proposed here. The issue still seems to be unsettled since the radiochemical difficulties of the determination of the  $\text{Sr}^{90}/\text{Sr}^{90}$  ratio are large and may well have introduced sizable errors into some of the reported values for this number and since it apparently is possible to account reasonably well for the observed fallout distribution on the present uniform stratospheric fallout theory as shown in the present paper. The critical difference between the two theories is in the matter of the age of the fallout. Better and more significant results probably will be available soon using the  $\text{Ba}^{140}/\text{Sr}^{90}$  ratio which for both radiochemical and lifetime reasons is more suitable than  $\text{Sr}^{90}/\text{Sr}^{90}$ .  $\text{Ba}^{140}$  has a half life of 12.8 days which is more appropriate to distinguishing between an expected fallout age of perhaps 30 days on the one hand and of about 1 to 2 years on the other, than is the  $\text{Sr}^{90}$  half life of 51 days. The radiochemical procedure for  $\text{Ba}^{140}$  is very similar to that for  $\text{Sr}^{90}$  and both are more sensitive and reliable than the  $\text{Sr}^{90}$  procedure which is particularly susceptible to errors from radioactive impurities such as other fission products which may have been imperfectly separated. Both  $\text{Ba}^{140}$  and  $\text{Sr}^{90}$  are measured by short-lived radioactive daughters of characteristic half life and which can be repeatedly removed and measured since a new supply is grown into equilibrium each time a separation has been made.

The importance of settling this point is obviously considerable for both meteorology and geophysics and certainly for the understanding of the mechanism of radioactive fallout. Perhaps the  $\text{Ba}^{140}$  data will show the truth to lie somewhere between the two mechanisms.

#### Bomb carbon 14

Rafter<sup>16</sup> and Rafter and Fergusson<sup>17</sup> have shown carbon 14 increases in surface air at Makara in New Zealand and in New Zealand woods and ocean carbonate as shown in figure 14. This additional carbon 14 is due to bomb-generated neutrons which react with air nitrogen to produce it. They find about 2.1 percent increase per year.

Williams<sup>18</sup> of Humble Oil & Refining Co., finds  $3.0 \pm 0.5$  percent per year in Texas tree rings, figure 14, and de Vries<sup>19</sup> in Holland, and Munnich<sup>20</sup> in Heidelberg, Germany, both report increases. The carbon 14 increase in the flesh of the land snail, *Helix pomatia*, amounted to 4.3 percent between November 1953 and June 1957 in Holland, while an increase of about 10 percent during 1955 and 1956 occurred in Heidelberg in various biosphere samples.

At a rate of 2.5 neutrons per 200 Mev. of energy release, 1 megaton would generate  $3.2 \times 10^{26}$  carbon 14 atoms. The best estimate, keeping in mind that a substantial amount falls back as calcium carbonate, would be that about  $10^{26}$  carbon 14 atoms have been introduced into the atmosphere, mostly into the stratosphere. The estimate of 2.5 neutrons per 200 Mev. energy released is higher than an earlier estimate based on an assumed 15-percent escape efficiency,<sup>21</sup> the later value being based on firmer information. It also attempts to weigh fusion and fission as they have actually occurred.

About  $9.4 \times 10^{26}$  carbon 14 atoms are normally present in the stratosphere due to cosmic ray production.<sup>22</sup> This figure assumes 22 percent of the atmosphere to be in the stratosphere. Therefore, with worldwide stratospheric circulation, the rise in the stratosphere should be about 100 percent as was found in a few measurements made on samples collected in October 1956. Further measurements are in progress.

<sup>14</sup> L. Machta, Indianapolis meeting, AAAS, December 1957 (in press).

<sup>15</sup> "Atom Bomb Effect. The Natural Activity of Radiocarbon in Plants, Shells, and Snails in the Past Four Years," H. de Vries, Science (in press).

<sup>16</sup> K. O. Munnich, private communication.

<sup>17</sup> "Radioactive Fallout and Radioactive Strontium," W. F. Libby, Science 123, 657 (1956).

<sup>18</sup> "Radiocarbon Dating," W. F. Libby, University of Chicago Press (1955), second edition.

In the troposphere in the 3 years since the 1954 Castle test at the 10-percent per year figure used for fallout, about  $3 \times 10^{27}$  carbon 14 atoms should have descended, or about  $1 \times 10^{27}$  carbon 14 atoms per year. The average carbon 14 inventory in the troposphere is  $3.3 \times 10^{28}$  without including the ocean or biosphere, so the observed carbon 14 rise might be as high as 3 percent per year as appears to have been observed.

If mixing with the biosphere and top ocean above the thermocline occurred immediately, according to Arnold and Anderson (35) who gave  $0.2 \text{ g/cm}^3$  in the top 100 meters of the ocean, the total tropospheric reservoir would be  $7.5 \times 10^{28}$ , giving an expected rate of increase due to the bombs of 1.3 percent per year which is in fair agreement with the observations if we assume the mixing with the ocean and the biosphere, particularly the former, is not quite instantaneous.

The main points are that the ratio of the Northern to Southern Hemisphere effect here is not enormous and fits fairly well with the notion that stratospheric gases have a residence time not too different from that of the ultrafine worldwide fallout particles.

In addition, Fergusson<sup>17</sup> has recently found in studying fossil  $\text{CO}_2$  and its effect on reducing the carbon 14 content of the biosphere that the mean life of a  $\text{CO}_2$  molecule before being absorbed from the tropospheric air into the oceans and biospheres is perhaps 2 years and that north to south mixing of the fossil  $\text{CO}_2$  occurs in less than 2 years.

Consequently, it seems clear that the 10-year residence time for stratospheric gases before descent into the troposphere seems to fit data for carbon 14 from bombs as well as the strontium 90 and cesium 137 fallout data.

Figure 15 gives up-to-date data on the occurrence of tritium in rainwater in the Chicago area.<sup>23</sup> It is clear that whereas strontium 90 and probably carbon 14 remain in the stratosphere for years, the tritium from high yield thermonuclear detonations does not, but descends in a matter of 1 or 2 months. This most probably is due to the enormous mass of water carried into the stratosphere by the fireballs of detonations in the moist tropospheric air. The characteristic white mushroom cloud is evidence of the formation of ice crystals in the cold stratospheric air, which if large enough to be seen in this way must certainly be large enough to fall into the troposphere where they melt and join in the ordinary phenomena; i.e., fall out as rain or snow. Thus a large fractionation relative to fission products and radioactive carbon dioxide occurs. Of course, there probably is some entrainment of fission products on the surfaces of the falling ice crystals by the Greenfield Brownian motion accretion mechanism. In fact, it is known that about 1 percent of megaton yield off-site fallout occurs in the early banded tropospheric manner. This may be due to this entrainment and thus one would expect that the latitudinal distributions of early tropospheric fallout of both fission products and tritium water from megaton yield bombs fired in the troposphere<sup>24</sup> should be identical. No satisfactory data are now available to check this point. In the calculations in this paper the figure of 1 percent for tropospheric contribution from megaton yields has been used.

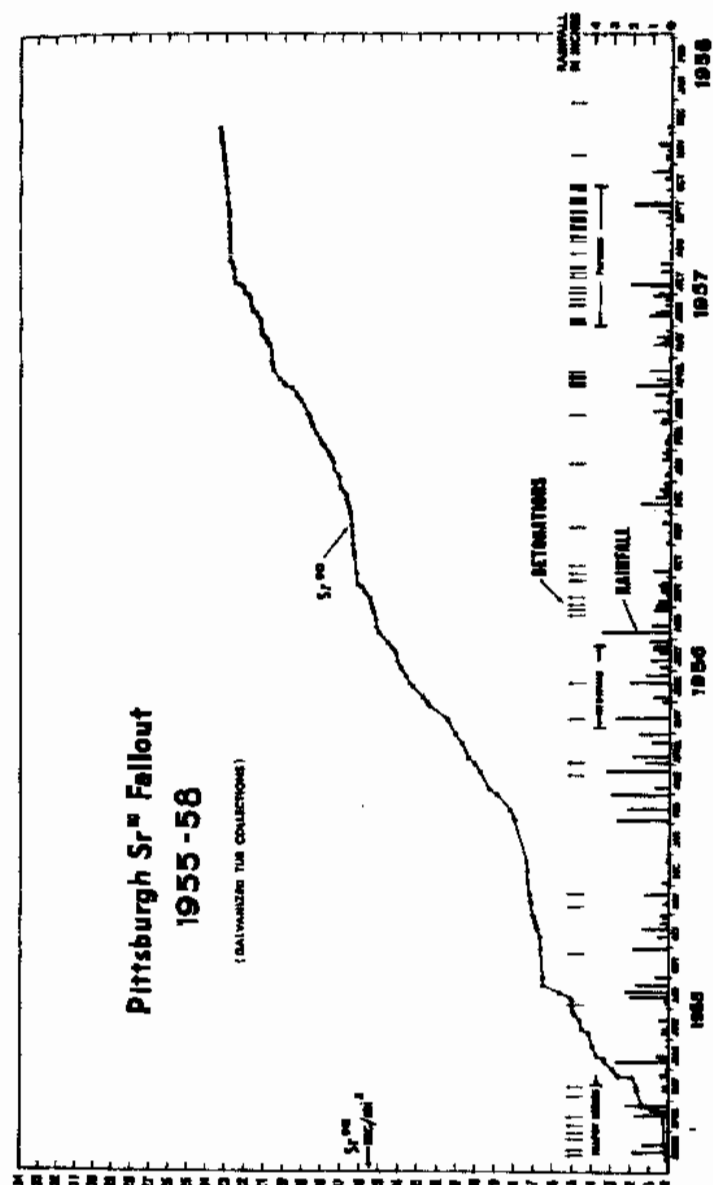
#### III. CONCLUSION

The more recent data, particularly on bomb carbon 14, when taken together with the earlier data on bomb fission products and tritium, give us some confidence in our present understanding of the fallout mechanism. All of these observations and considerations afford unprecedented opportunities for the study of meteorology and geophysics, particularly in an international cooperative effort such as the International Geophysical Year.

<sup>23</sup> "Natural Distribution of Tritium," S. Kaufman and W. F. Libby, Phys. Rev. 88, 1337 (1954).

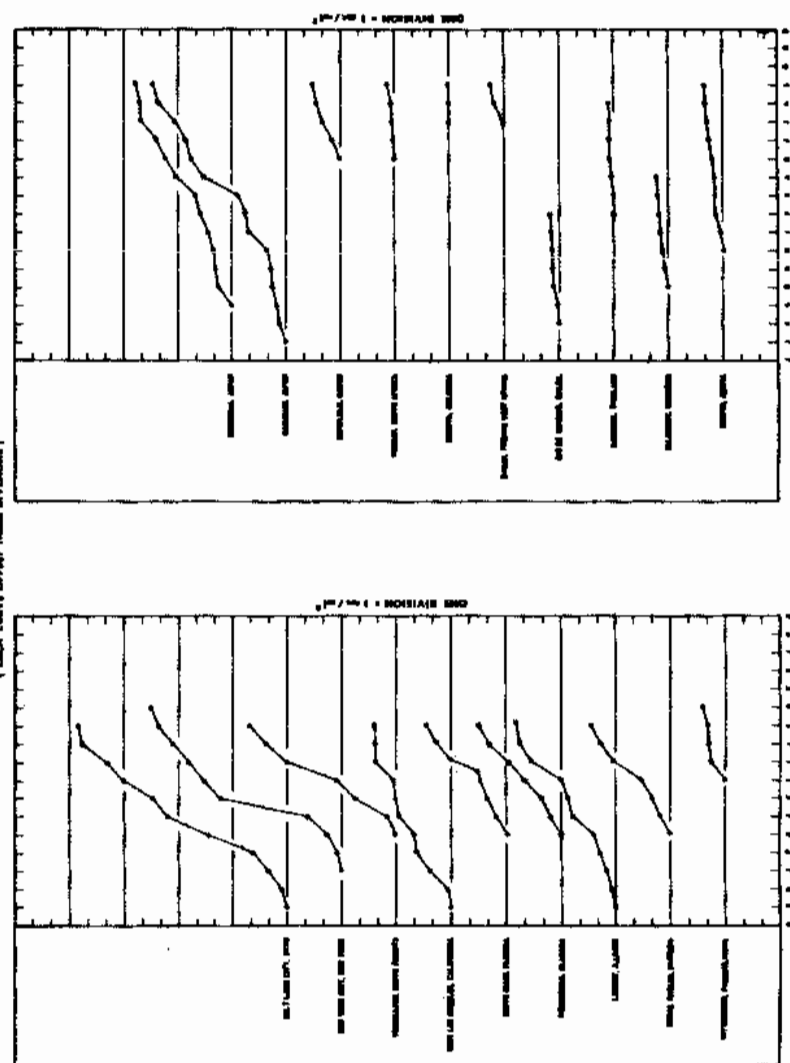
<sup>24</sup> "Continental Water Balance, Ground Water Inventory and Storage Times, Surface Ocean Mixing Rates and Worldwide Water Circulation Patterns From Cosmic-Ray and Bomb Tritium," F. Begemann and W. F. Libby, Geochimica et Cosmochimica Acta, 12, 277-296 (1957).





**Sr<sup>90</sup> FALLOUT**  
MONTHLY RAIN WATER COLLECTION  
MASS

(EACH CURVE OFFSET FROM PREVIOUS ONE)



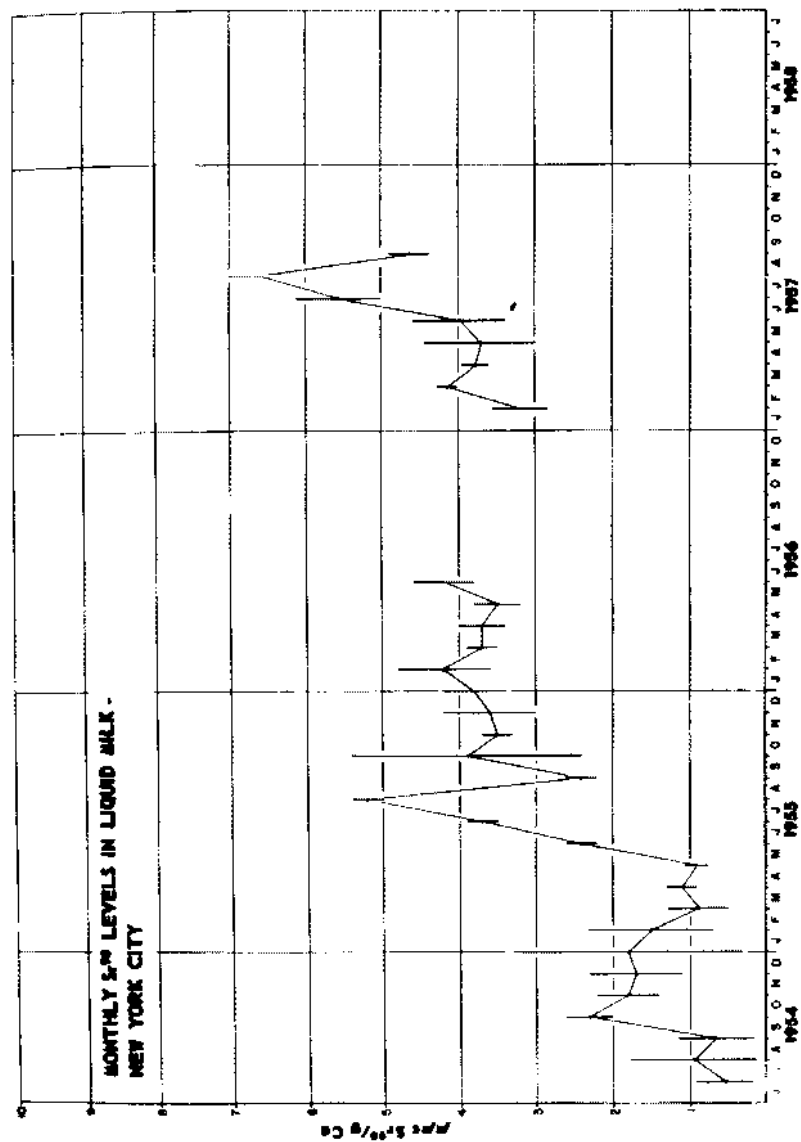


FIGURE 3

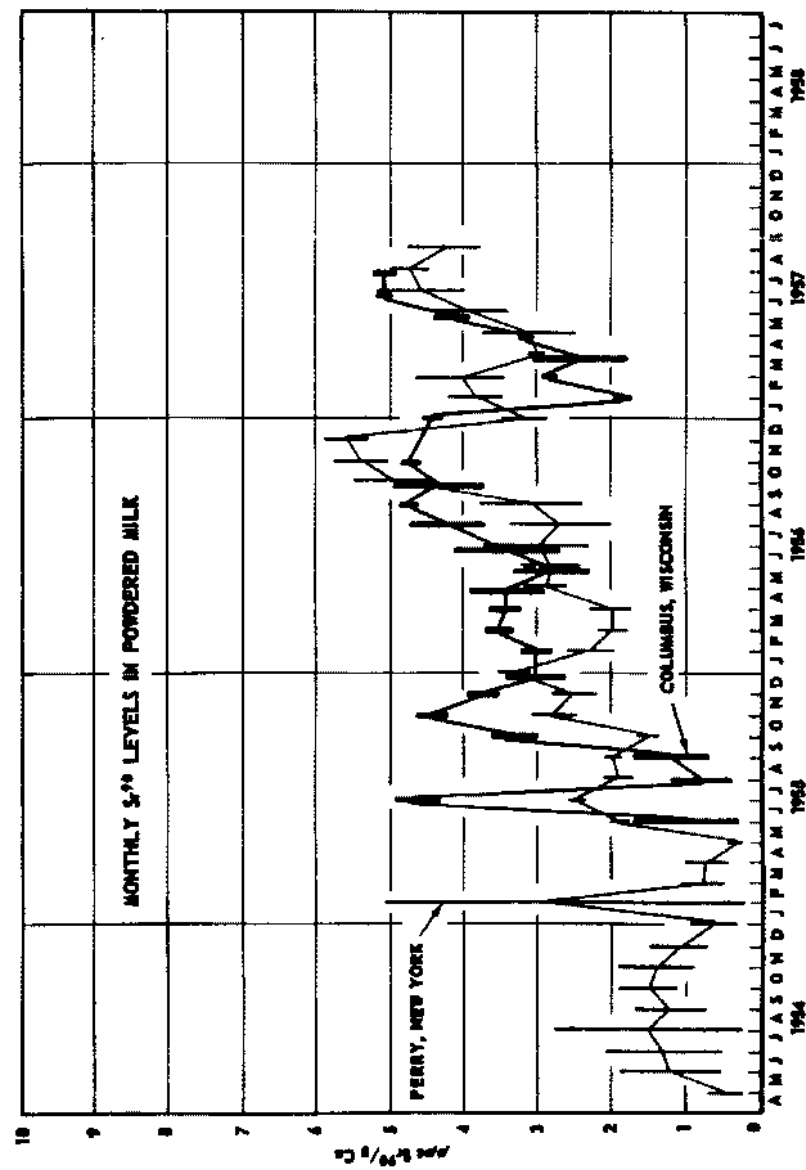


FIGURE 4

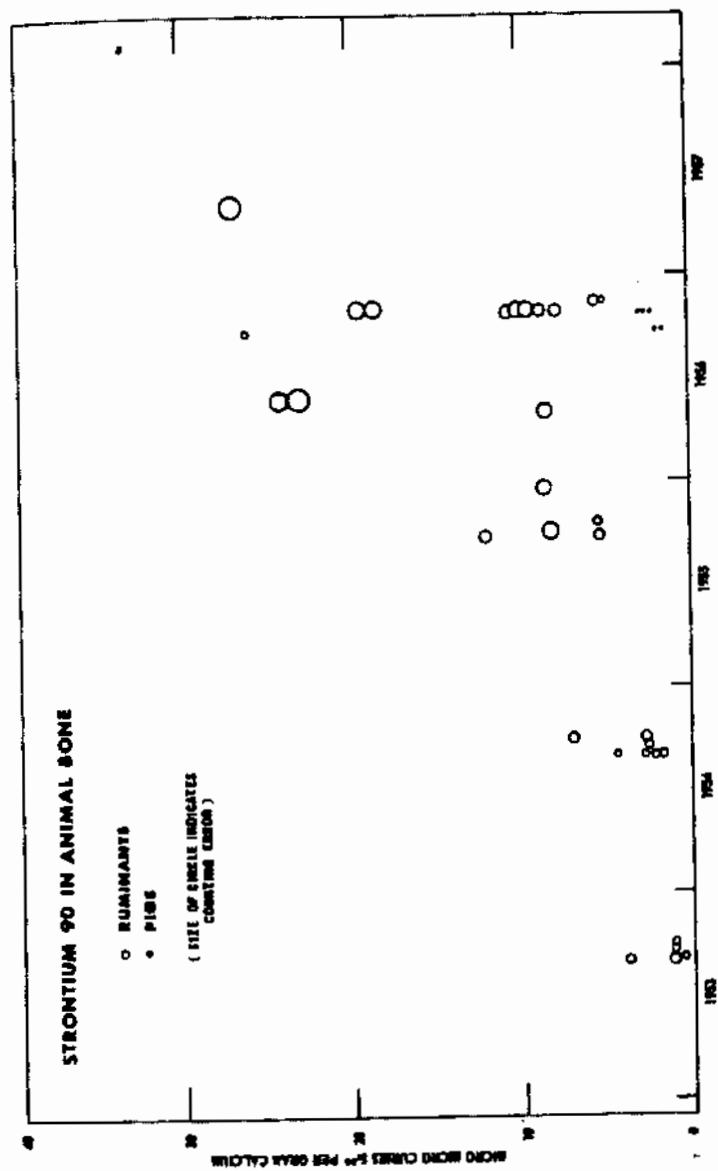


FIGURE 5

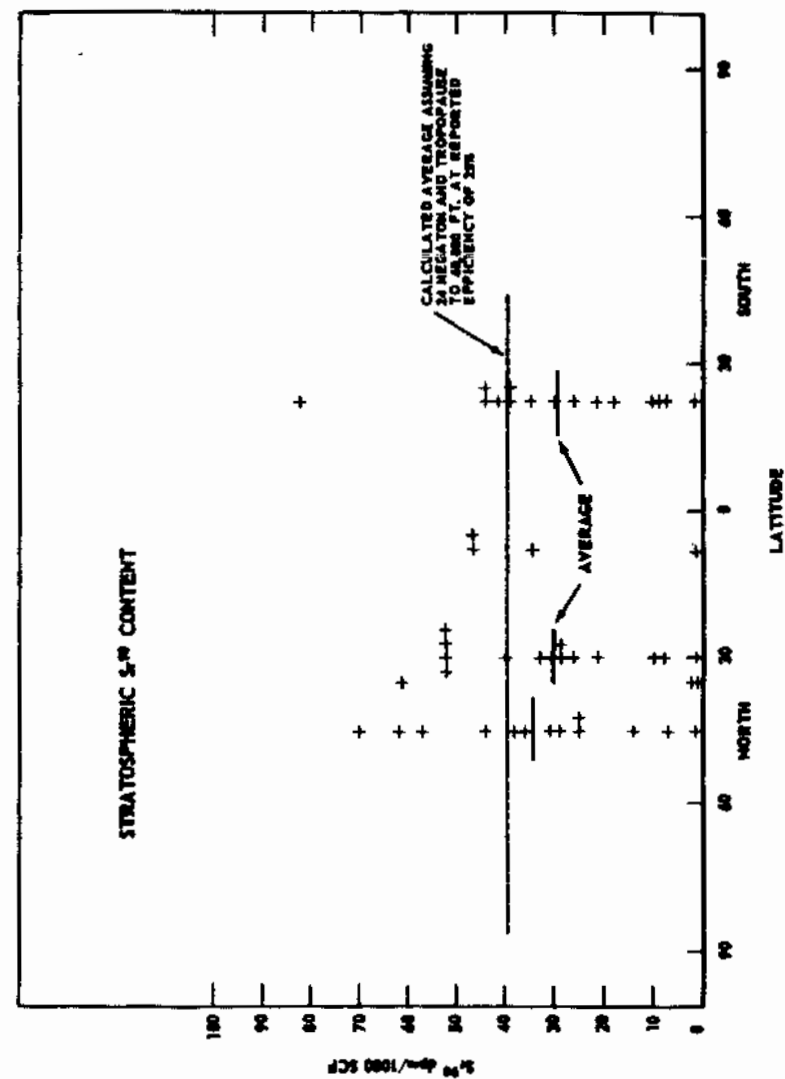


FIGURE 6

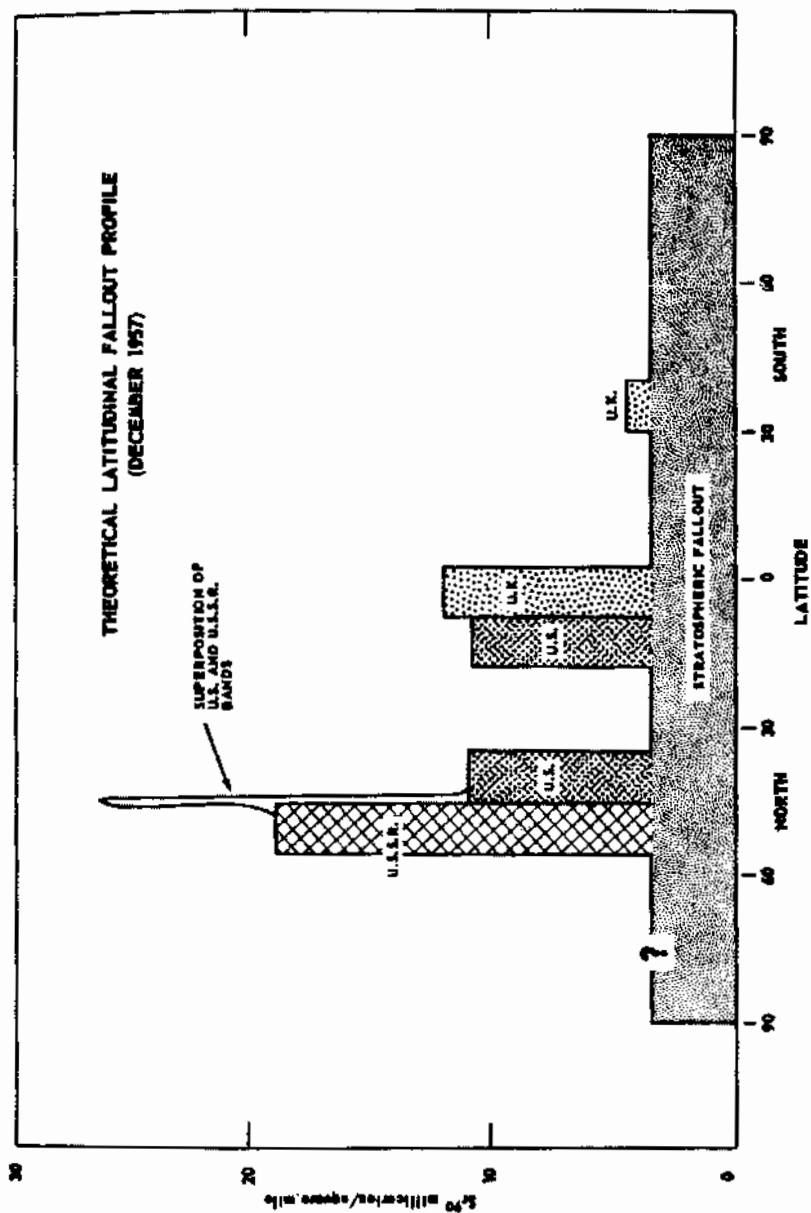


FIGURE 7

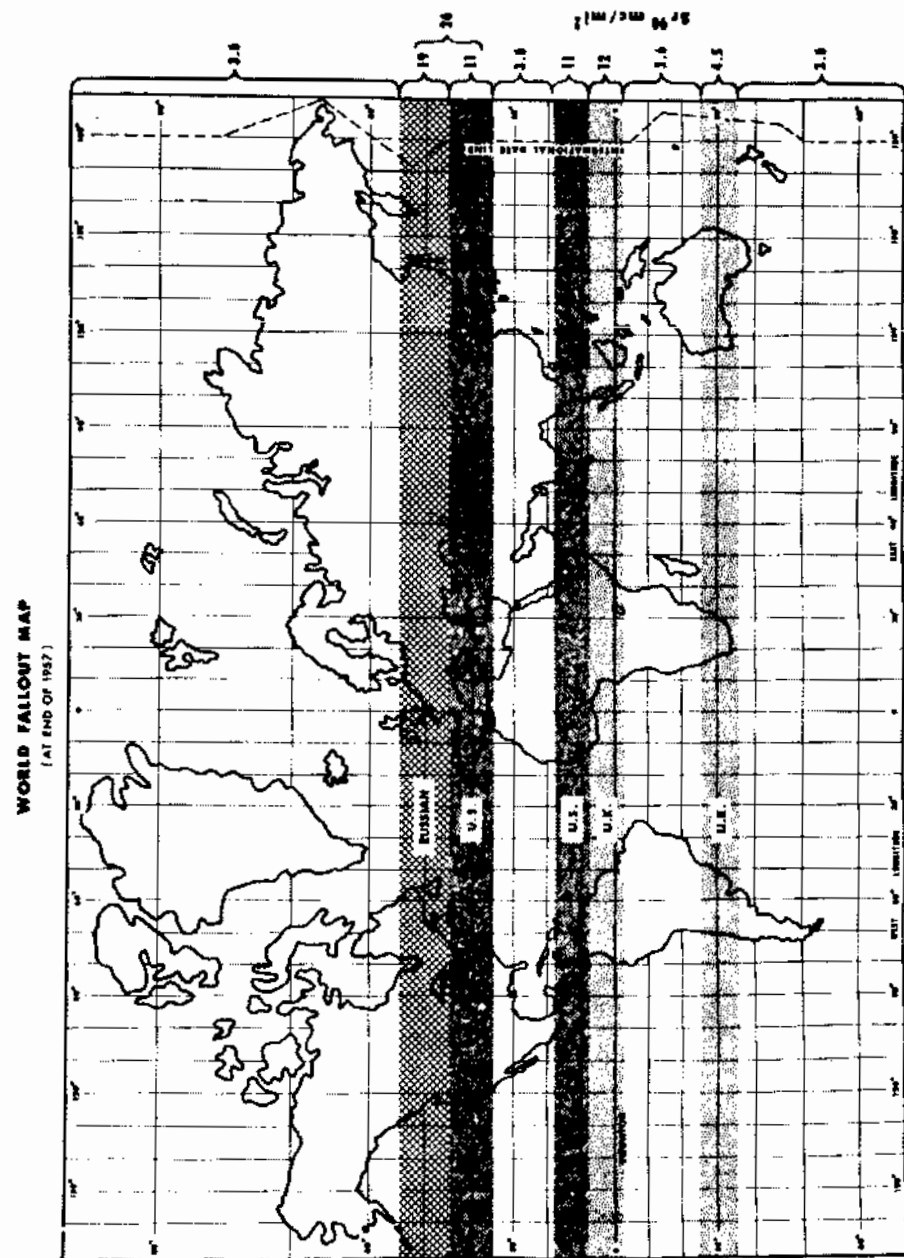


FIGURE 8

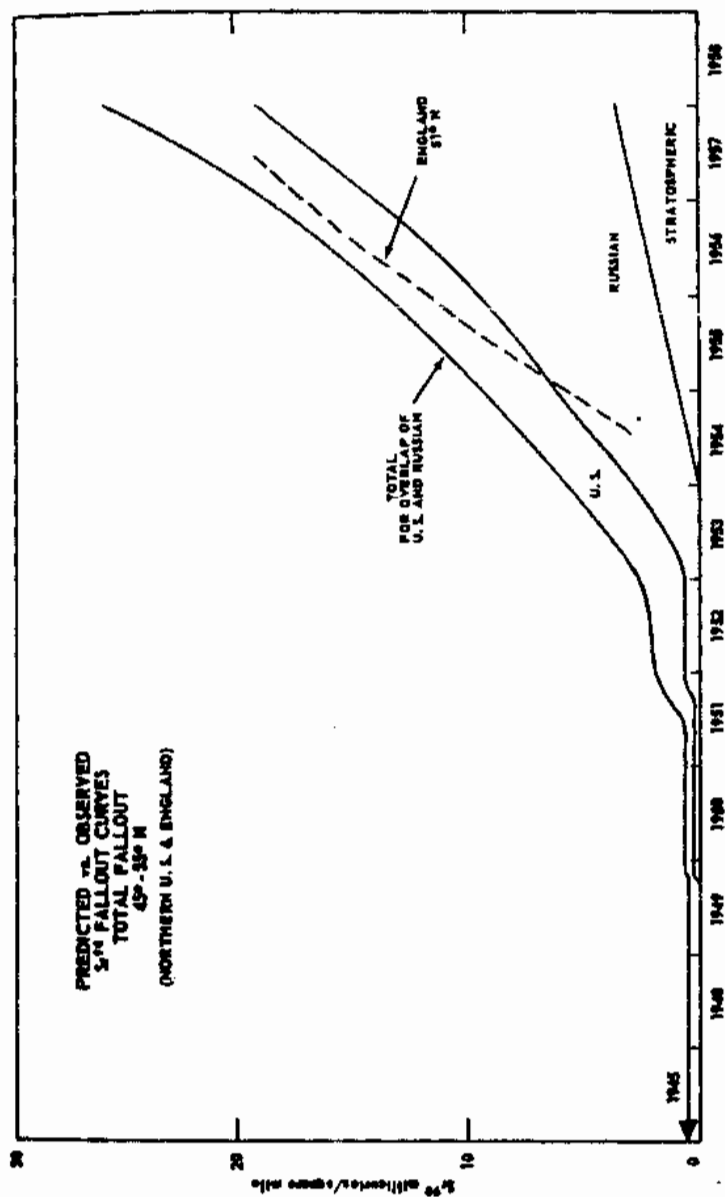


FIGURE 9

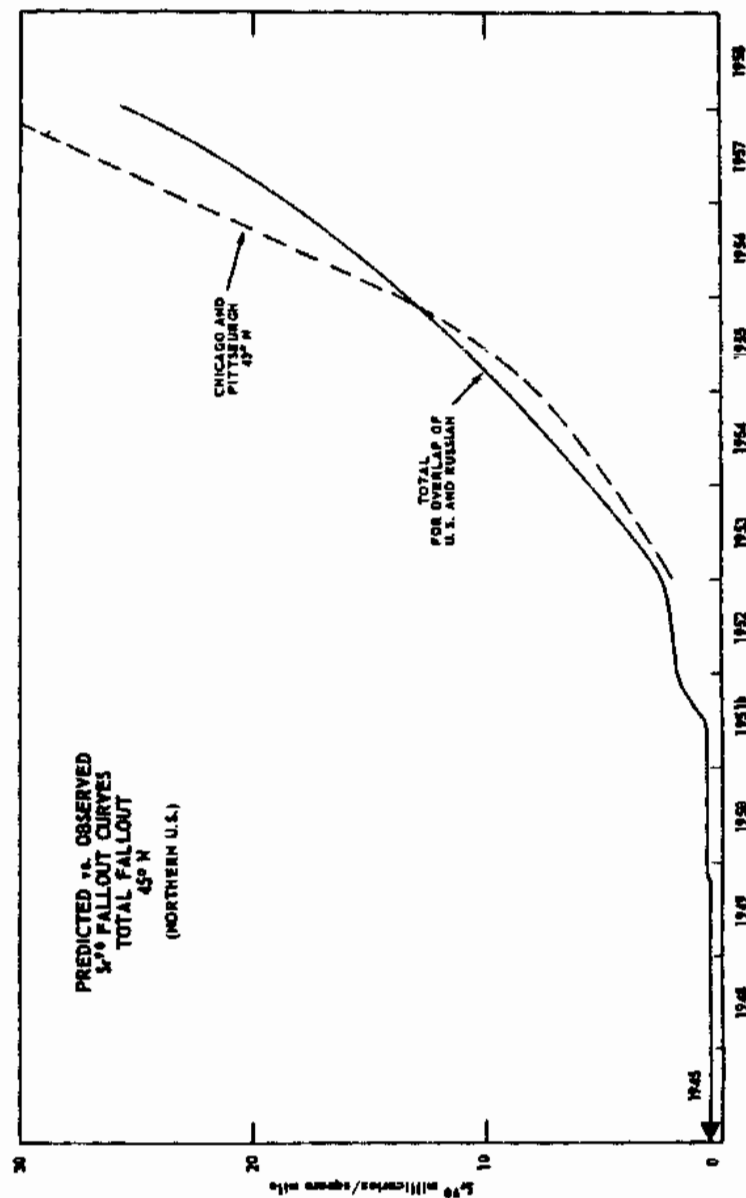


FIGURE 10

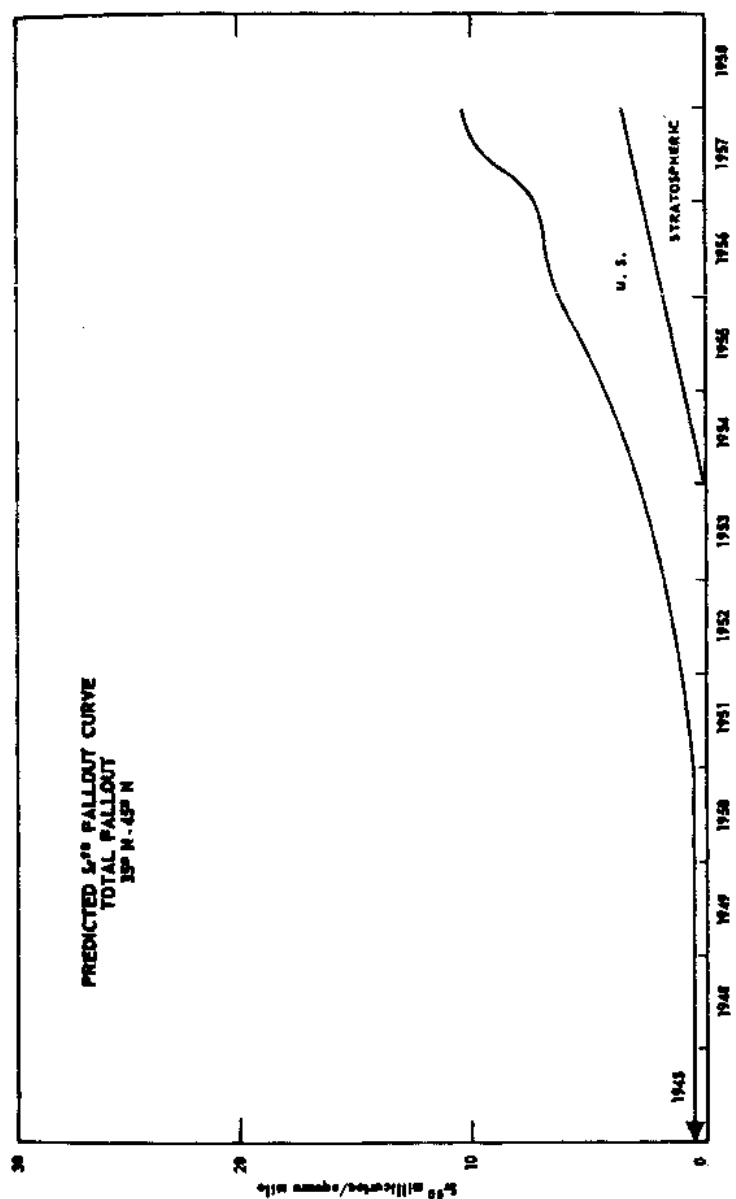


FIGURE 11

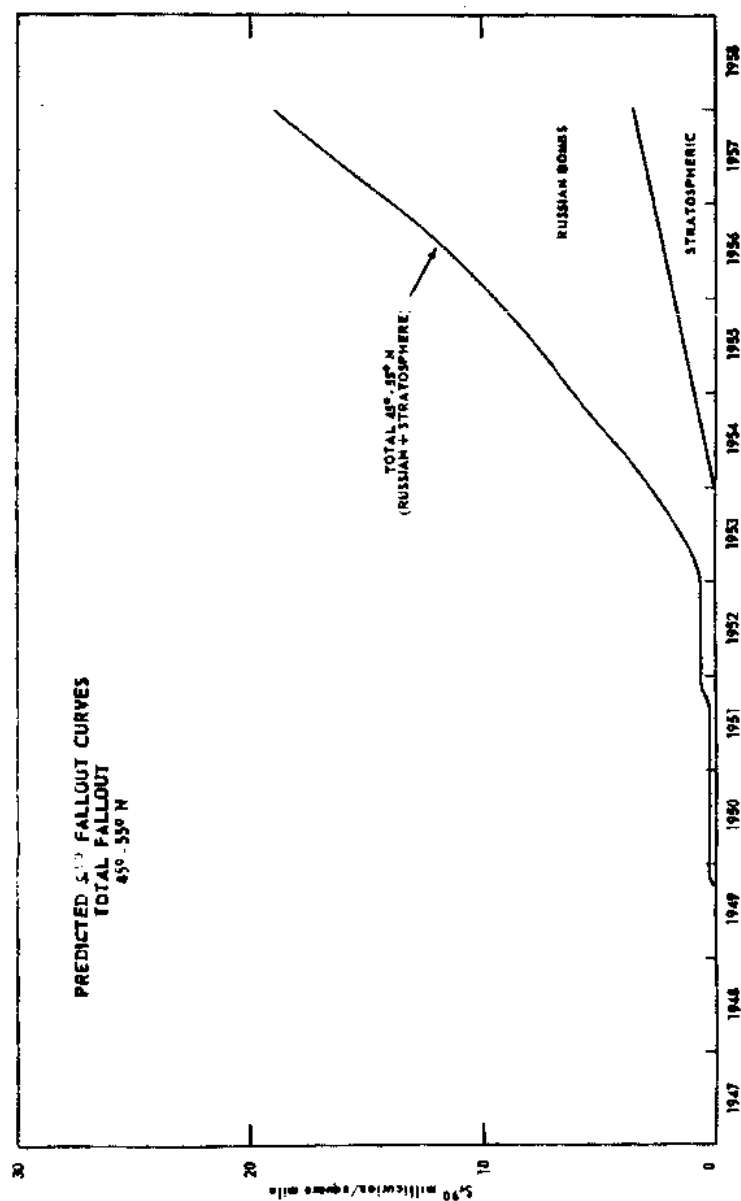


FIGURE 12

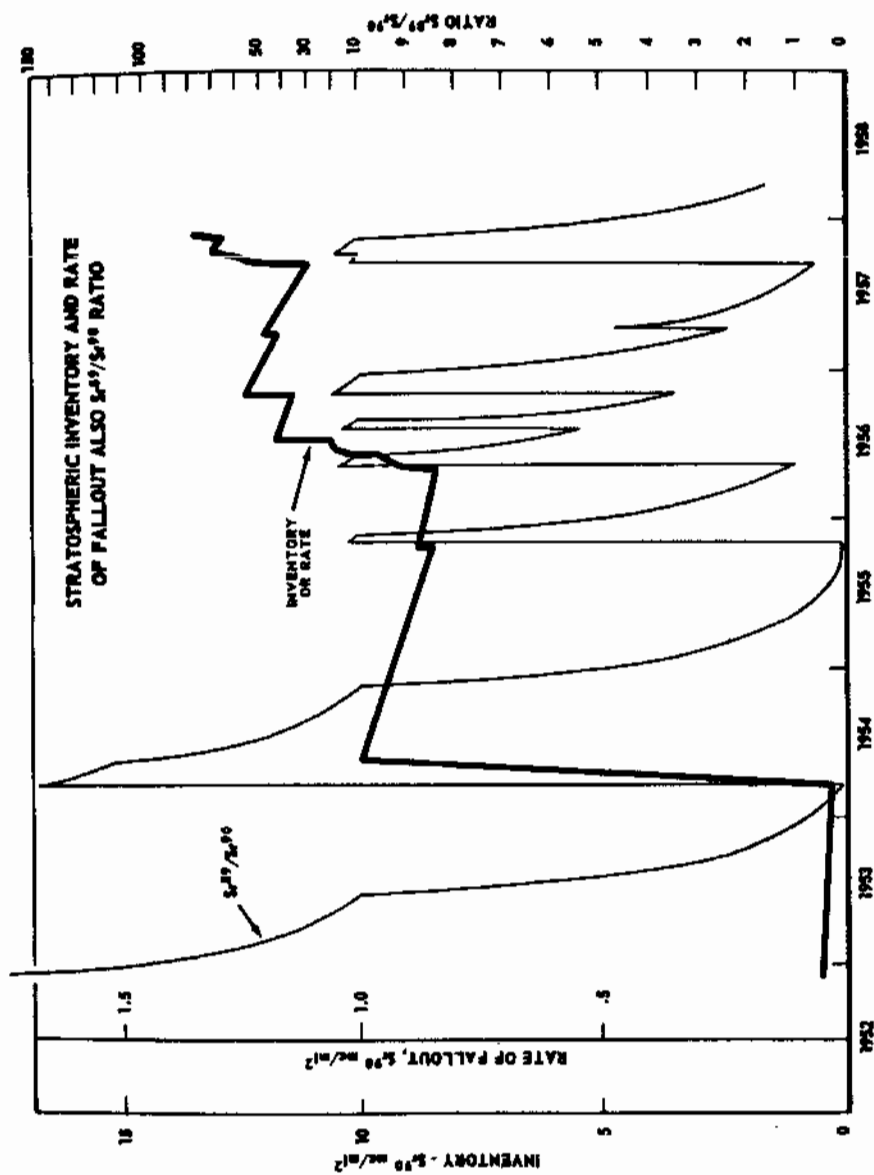


FIGURE 13

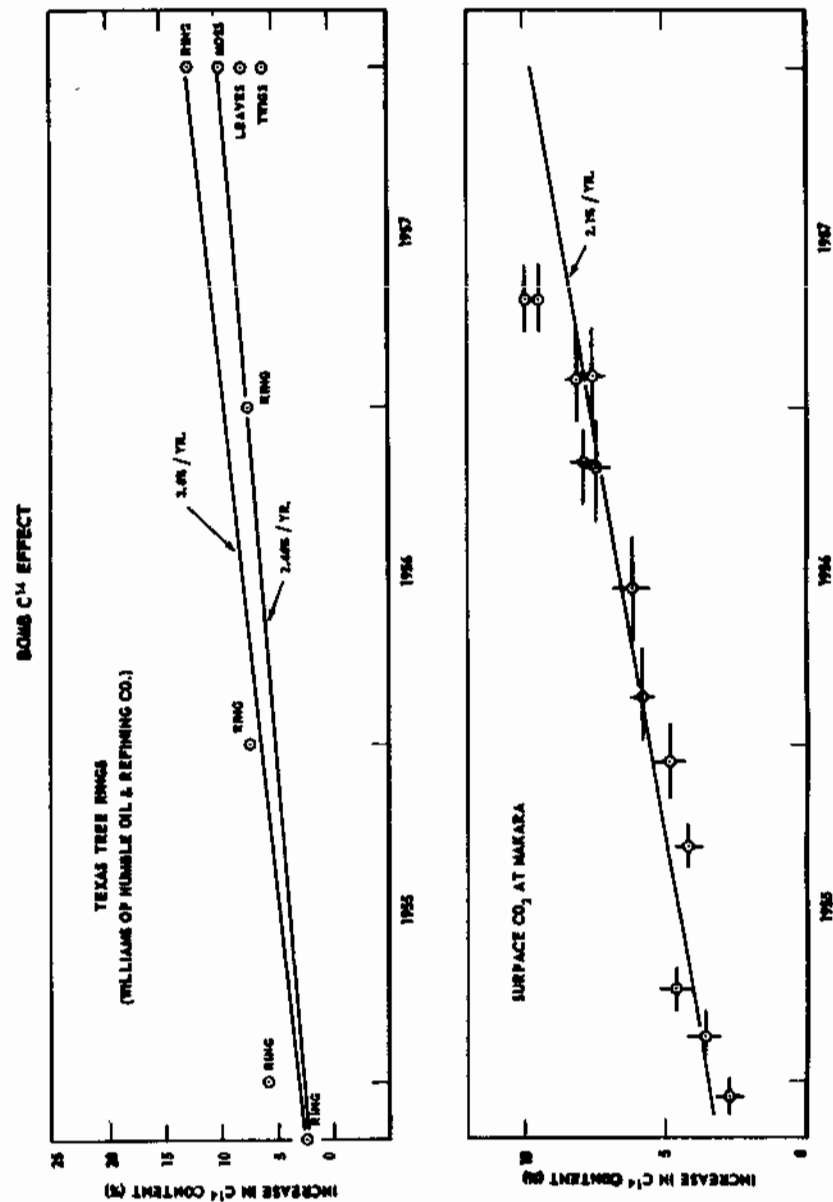


FIGURE 14

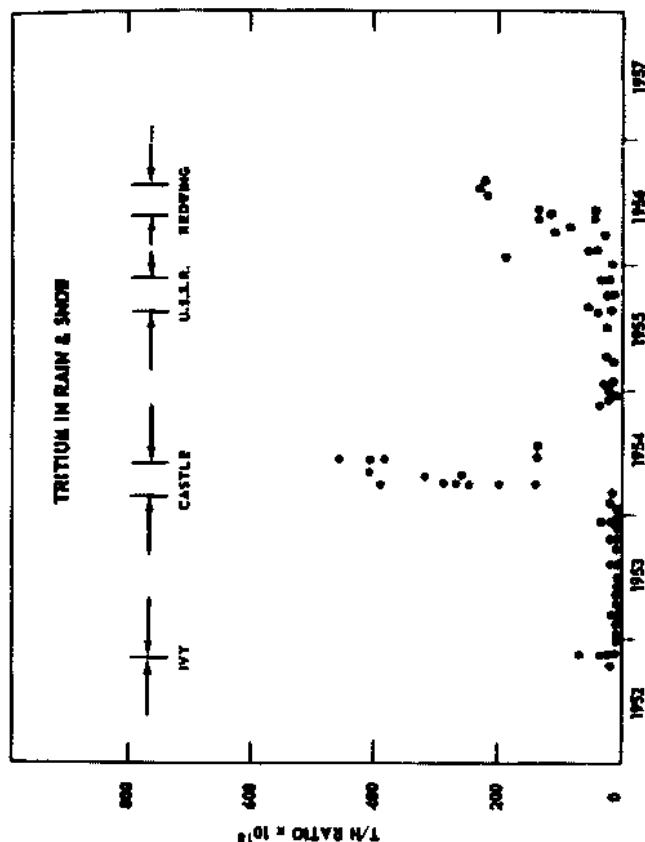


FIGURE 15

## RADIOACTIVE FALLOUT

Remarks prepared by Dr. Willard F. Libby, Commissioner, U.S. Atomic Energy Commission, for delivery at the University of Washington, Seattle, Wash., sponsored by faculty of the College of Engineering, faculties of the Departments of Chemistry and Physics in the College of Arts and Sciences, and the University Office of Lectures and Concerts, March 13, 1959

## I. INTRODUCTION

Radioactive fallout is the radioactivity produced by the detonation of nuclear weapons. It has been extensively studied and reported upon (1-30) and, in general, although certain questions remain unanswered, the broad characteristics of the behavior of radioactive fallout have been established. We might take a few minutes to review these.

The stratosphere, the top fifth of the atmosphere lying above 40,000 feet, plays an extremely important role. In fact, the fallout from megaton yield weapons occurs very largely from it while the troposphere is the medium which disseminates the fallout from kiloton detonations; thus, speaking broadly, stratospheric debris is from H-bomb detonations and the tropospheric fallout is from A-bombs. It is not that the yield of the detonation is determinative, but rather the altitude to which the fireball rises that determines the fallout rates. The megaton yield fireballs are so enormous that they stabilize at levels only above the tropopause—the imaginary boundary layer dividing the upper part of the atmosphere, the stratosphere, from the lower part, the troposphere—while the kiloton yield fireballs stabilize below the tropopause. The tropopause normally occurs at something like 35,000 to 55,000 feet altitude, although it depends on season and location. In other words, low-yield bombs fired in the stratosphere would be expected to give the same fallout rates as high-yield weapons do when fired in the troposphere—or on the surface. There is some small part of the fallout for megaton yield explosions which does not reach the stratosphere.

The stratospheric debris descends very slowly unless, of course, it is so large as to fall in the first few hours. This paper is concerned only with the worldwide fallout—that is, the fallout which does not occur in the first few hours and excludes the local fallout which constitutes the famous elliptical pattern which is so hazardous because of the intensity of its radiation at early times but which, in test operations, is carefully restricted to test areas. It is worth mentioning in passing that the local fallout may be the principal hazard in the case of nuclear war. Most serious attention should be paid to it in civilian defense programs.

## II. WORLDWIDE FALLOUT MECHANISM

The worldwide fallout from the stratosphere occurs at a slow rate. The rate of descent of the tiny particles produced by the detonations is so small that something like 5 to 10 years appears to be the average time they spend before descending to the ground, corresponding to an average annual rate of about 10 to 20 percent of the amount in the stratosphere at any given time. It is not clear as to just how they do finally descend. It seems possible that the general mixing of the stratospheric air with the tropospheric air, which occurs as the tropopause shifts up and down with the reason as well as what is brought about by the jetstreams, constitute the main mechanisms. The descent of the stratospheric fallout apparently is never due to gravity but rather to the bulk mixing of stratospheric air with tropospheric air which brings the radioactive fallout particles down from the stratosphere into the troposphere where the weather finally takes over. This mechanism makes the percentage rate the same for all particles too small to fall of their own weight—and the same as would be expected for gases, providing some means of rapidly removing the gases from the troposphere exists, so the reverse process of troposphere to stratosphere transfer does not confuse the issue.

The worldwide fallout from the stratosphere descends very slowly and one of the questions unanswered at this time is just at what rate it does descend. There have been various estimates from 10 percent per year to 20 percent or even higher. But everyone is agreed that the stratosphere does hold its radioactive fallout for a much longer time than the lower part of the atmosphere. In fact, the stratospheric material has a residence time of something like several years and we shall estimate, in the course of the discussion, that this figure is



something like 6 years, whereas the troposphere has a mean residence time of about 1 month with the lower 10,000 feet of it being washed clean on the average about every 3 days. Between 10,000 feet and the tropopause, which is at something like 35,000 to 55,000 feet, the residence time is perhaps 45 days for a mean time for the troposphere of about 1 month. Thus, we see that radioactive fallout which is injected into the troposphere is restricted to the general latitude of the detonations for the reason that the residence time is so short that it doesn't have time to mix appreciably latitudinally.

The principal mechanism for removal from the troposphere to the surface is rain. The tiny fallout particles hit cloud droplets and stick to them. Because the particles are so small (perhaps a few hundred atomic diameters), they are subject to a violent random jiggling motion due to collisions with air molecules. It is this motion which causes them to hit the cloud droplets. This motion is called the Brownian motion. In fact, for a particle 1 micron in diameter, Greenfield (28) calculates that the mean residence time in a typical cloud of water droplets of 20 microns diameter will be between 50 and 300 hours, that for a particle of 0.04 micron diameter it will be between 30 to 60 hours, and that for a particle of 0.01 micron diameter it will be between 15 to 20 hours. The theory calculates the diffusion due to the Brownian motion and says that it is just this motion induced by the collisions with the air molecules which makes possible the contact between the fallout particles and the cloud drops. Since this theory is based on first principles with the single assumption that the fallout particle sticks to the water droplet on impact—an assumption so plausible as to be almost beyond doubt—it is no surprise to learn experimentally that the Greenfield theory appears to be correct.

There is essentially no worldwide fallout in the absence of rainfall; i.e., in desert regions—except for a little that sticks to tree leaves, blades of grass, and general surfaces, by the same type of mechanism Greenfield describes in the case of clouds. Thus we see that it is the moisture in the troposphere which assures the short lifetime of the worldwide fallout particles and, that when the stratospheric air which contains essentially no moisture\* and, therefore, has no cleansing mechanism, descends into the troposphere, the tropospheric moisture proceeds to clean it up. On this model, we see that for submicron fallout particles, weather phenomena are controlling and that the bombs which have insufficient energy to push their fireballs above the tropopause will have their worldwide fallout brought down in raindrops in a matter of about 1 month on the average, in extreme contrast with the stratospheric material which apparently stays aloft for years on the average.

The contrast between these two lifetimes means that the concentration of radioactive fallout in the stratospheric air in terms of equal densities of air is always much higher than in tropospheric air. This has been experimentally observed to be true.

Data from measurements made at the surface as given in figures 1 to 5, inclusive, are calculated from surface air filter measurements made by the Naval Research Laboratory (29). Figures 1 and 2 present the mixed fission product data and figures 3, 4, and 5 give data obtained by analysis of the filters and calculated as rates of strontium 90 fallout. The calculation of fallout rates from the air-filter data was made by assuming the mean residence time in the lower atmosphere to be 3 days. Ten thousand feet is estimated to be the average thickness of the air lying below the rain origin. The observed fallout rate in Pittsburgh for the same period of time checks very well with the calculated rate for Washington, D.C., from the air-filter data.

Tables I and II give the results of similar calculations for both mixed fission products and air-filter strontium 90 data for various latitudes. The theoretical values are those calculated from the model, assuming the average tropospheric residence time of 1 month and of the stratospheric material 10 years.

The mean average concentration in the lower atmosphere during the last months of 1957 and the first few months of 1958 was about 1 disintegration per minute per 100 standard cubic meters or 0.26 per 1,000 standard cubic feet in the Northern Hemisphere. At this time the content of the higher troposphere would have been expected to be about 15 times this or 3 to 4 disintegrations per minute per thousand standard cubic feet. This would be expected for air just below the tropopause in the higher levels of the troposphere.

\*The total water in the stratosphere is about 0.01 gms/cm<sup>2</sup>, or less, while that in the troposphere is about 2 gms/cm<sup>2</sup>, 200 times as much.

We understand the broad problems of the residence time and the scavenging mechanism for the troposphere. In brief, fallout comes down from the troposphere mainly with rain; as a consequence of accretion in clouds by the rapid diffusive movements of the tiny particles causing them to hit the cloud droplets. By the same type of mechanism, contact with any surface such as grass, leaves, trees, etc., also will cause deposition. As a result of this, the mean residence time in surface air up to about 10,000 feet is about 3 days and the average residence time for the whole troposphere is about 1 month. The residence time for the higher part, the top 20,000 to 30,000 feet, would be something like 45 days with an expected steady state concentration perhaps 10 to 15 times the value at the surface.

Now let us turn to the question of the residence time in the stratosphere. This is a very difficult one in the absence of reliable data on the actual quantity of bomb debris in the stratosphere. In the absence of firm direct measurements, one makes estimates of the stratospheric content by adding the amount of radioactivity which is injected, subtracting the fallout and subtracting for the decay and thus calculating the difference. In this way numbers are derived which can be used to compare with the inadequate information that is available on stratospheric content. Now it isn't always clear just what fraction of a bomb falls out locally and what fraction goes into the stratosphere and troposphere. However, certain empirical rules have been used to estimate these numbers. These are (1) the megaton bomb debris which does not fall out locally in the first few hours is assigned 99 percent to the stratosphere and 1 percent to the troposphere; (2) local fallout is assumed to be 80 percent for land surface shots and 20 percent for surface water shots and negligible for air shots; (3) all kiloton shots are assigned to the troposphere; (4) it is assumed that the latitudinal spread of tropospheric bomb clouds is only 10 degrees with a sharp step function rather than a normal error curve distribution and the residence time for this fallout is taken to be 1 month as described above. On the basis of these assumptions, knowing the yields and types of bombs which have been fired, we estimate the total stratospheric inventory and on the basis of various reasonable stratospheric residence times predict the stratospheric fallout over the earth's surface for an averaged intensity of rainfall. Figure 6 gives the stratospheric inventory for strontium 90 as deduced in this manner up to January 1, 1959, calculated on the basis of two assumed residence times—5 and 10 years.

It is interesting to note the tremendous rise in October of last year due to the Russian test series in the polar regions, as shown in figure 6. This makes possible a searching test of all the theories of stratospheric storage, mixing and fallout and in particular of an interesting new one advanced recently by E. A. Martell (22). Dr. Martell's theory is that whereas equatorial shots would have their radioactive debris distributed uniformly throughout the stratosphere and might well come down according to a residence time of 5 to 10 years, this is not true for shots made in the polar regions as for the Russian tests. He suggests that there may be a distinction to be drawn for these as compared to the United States-British tests carried out near the Equator. For the polar shots he suggests a much shorter residence time—1 year or less—and over the northern latitudes of the particular hemisphere involved. The Russian October series makes an immediate and definitive test possible. In table II we display the strontium 90 fallout rate for northern latitudes expected now—on Dr. Martell's theory—of some 32 millicuries of strontium 90 per square mile per year with an average age such that the ratio of the 51-day strontium 89 to strontium 90 should be 115 in November decreasing to 51 in January as compared to expected rates on the older uniform distribution theory of 2.0 or 5.1 millicuries per square mile per year depending on whether the stratospheric residence time be taken as 10 or 5 years respectively and with the strontium 89 to strontium 90 at 51 for November, 36 for December, and 26 for January 1959.

In the table data are given for November for Pittsburgh, December for Westwood, N.J., and January for Washington, D.C., which, as you see, fall somewhat intermediate between the two theories, perhaps more closely fitting the old theory, particularly insofar as the strontium 89, strontium 90 values are concerned. At the present time it does not seem to be possible to decide definitely between the two alternatives, though the next few months should give us adequate data to distinguish between them.

In order to better delineate and understand the mechanism by which stratospheric fallout occurs the Atomic Energy Commission added the isotopes tungsten 185 and rhodium 102 to some of the nuclear devices exploded in the

Hardtack series last summer. Tungsten 185 with a half life of 74 days was produced in a number of detonations over silica sand. Underlying the study of tungsten 185 is the hope that by determining the contribution of a single equatorial test series in all parts of the world it would become possible to distinguish among the different models which have been proposed: (1) the one by the author in which the stratospheric material is assumed to mix uniformly over the world and then fall out at a rate corresponding to a residence time of 5 to 10 years or something intermediate to be determined; (2) the one which Dr. Machta is proposing (similar to a model suggested earlier by Dr. Stewart) is as follows: There are two transport mechanisms in the stratosphere; diffusive mixing and bodily transport. The latter is a poleward drift in the stratosphere accompanied by sinking motion in the temperate and/or polar latitudes. The drift is sufficiently marked relative to the mixing to result in the main exodus from the stratosphere to occur in the temperate or polar latitudes. The removal from the stratosphere takes place primarily in the spring portion of the year and least in the autumn. The rate of removal is a function of the time and place of injection and can vary with time from the same source. Thus, Dr. Machta agrees with Dr. Martell on the shorter residence time of debris injected into the stratosphere by the U.S.S.R. He considers exchange through the tropopause break to be only one of several possible modes of exit of stratospheric air into the troposphere; (3) the theory of Dr. Martell that uniform mixing of the stratosphere vertically and horizontally similar to the first model occurs for equatorial shots but that for a polar shot the mixing is confined to the hemisphere.

The rhodium 102 has a half life of 210 days and was released chiefly in the stratosphere. Thus this isotope will allow us to measure the stratospheric mixing time from the data which will become available as a result of the sampling of rainfall over the world and the various programs for taking air filter samples of both the stratosphere and the troposphere. These data are not yet available but it might be interesting just to predict the order of magnitude one would expect in rainfall. By assuming perfect mixing in the stratosphere in a period of something like 3 months over the whole earth, then it works out that 10 megacuries of an isotope would give something like 20 disintegrations per minute for 1,000 standard cubic meters of surface air, a readily detectable quantity.

There are preliminary data already indicating that as early as October 31 samples for the lower stratosphere near the equator at about 12° N. showed the rhodium 102 isotope. In other words, the vertical mixing in the stratosphere had occurred rapidly. This is one of the serious assumptions which the models have in common. There appears to be a considerable speed with which the stratosphere mixes, particularly model one assumes essentially instantaneous mixing though, of course, as shown in the above remark one need not do this and perhaps 3 months' time would be a reasonable figure to use.

The apparent age of the fallout is measured by the  $\text{Sr}^{90}/\text{Sr}^{90}$  and  $\text{Ba}^{140}/\text{Sr}^{90}$  ratios. Strontium 89 with a 51-day half life and barium 140 with a 13-day half life give independent measures of the age. In figure 7 the results of extensive measurements on the strontium 89/strontium 90 ratio, as shown by rain samples collected monthly at various places all over the world are plotted together with the values predicted by the simple uniform theory for 40° N. latitude and for pure stratospheric fallout. According to the model, stratospheric fallout is the principal type occurring throughout most of the Southern Hemisphere and in certain parts of the Northern Hemisphere which happen not to have been in the path of tropospheric debris. The theoretical calculation is made by taking the various contributions to the stratospheric reservoir and multiplying by their calculated strontium 89 to strontium 90 ratios (new debris is taken as having a ratio of 180 and the half life of strontium 89 is taken as being 51 days with, of course, strontium 90's half life being 28 years). In this manner the expected  $\text{Sr}^{90}/\text{Sr}^{90}$  ratio of fallout from the stratosphere is calculated. It has a fluctuating value due to injections from weapons tests but it rapidly settles down at all times prior to October 1958 to something like 5 to 10 units.

The tropospheric debris, on the other hand, having a mean residence time of only 1 month has a much higher strontium 89 to strontium 90 ratio. In making the calculation for the total expected fallout at any given position the amount of tropospheric debris is calculated by the rules given previously and the average taken. Similar calculations are done with barium 140 which has a half life of 12.8 days. Since it is a much shorter lived fission product, it affords

a possibility of revealing details which the longer lived strontium 89 cannot show. Figure 8 gives detailed data for the  $\text{Sr}^{90}/\text{Sr}^{90}$  ratio for our most carefully conducted rain fallout study, the Pittsburgh study. The theoretical curve is shown in the figure and again the agreement seems to be satisfactory. Figure 9 shows the analogous data for the barium 140-strontium 90 ratio in the Pittsburgh rain, and figure 10 shows recent fallout data for Pittsburgh and Westwood, together with the strontium 89 to strontium 90 and the barium 140 to strontium 90 ratios for Westwood. Finally, figure 11 shows the worldwide rain deposition data for monthly collections in various places over the world. These data correspond to the strontium 89 to strontium 90 ratios given in figure 7. All of these data are given in reference (4), that is HASL-42.

It is clear from figures 7 through 11 that there is a strong correlation between the strontium 89 to strontium 90 ratio and the occurrence of test series as shown on the bottom of the figures, and the success of the simple theory in predicting and accounting for the strontium 89 to strontium 90 ratios indicates that it is quite likely that a good part of the extra fallout in latitudes in which testing occurs, such as the middle northern latitudes is due to tropospheric fallout and may not be due to Dr. Machta's mechanism of preferential stratospheric drip in these middle latitudes.

In order to alleviate the abruptness of the step-function type of assumption in the model proposed by the author, calculations were done assuming that after the first month, tropospheric debris spread out to cover a band much wider than in the first month and, in fact, would cover an entire hemisphere. In this way, theoretical fallout curves were obtained which show the total predicted fallout at various latitudes assuming the average annual rainfall. It is always necessary to remember that particularly arid places will necessarily have low fallout and one should realize that this leads to other places having more fallout than they otherwise would have had. This broad band theoretical model may fit the observations somewhat better than the narrow band model presented earlier.

Figure 13 gives the latitudinal profile of total fallout from the narrow band step function calculation and figure 12 the broad band fallout curve. The important question is whether these predictions agree with observations. A first and most important point is that the data must be valid and not due to local fallout. Most are for the United States and the question is whether fallout is somewhat high because of the proximity of the Nevada test site. In table III we compare United States and foreign soil strontium 90 content for the year 1956, the foreign-soil samples having been taken in the same latitude band and at the same time. It is clear that the difference is large and amounts to about 11.4 millicuries per square mile which corresponds to some 340 kilotons of local fission fallout over the area of the United States, a reasonable figure. In other words, the sharp division between local and worldwide fallout is probably somewhat artificial and the U.S. test site being close to many of the sampling stations in the United States has caused the U.S. data to be high as compared to the worldwide average. Therefore, in comparing the theoretically predicted fallout with observation we choose to use only foreign-soil data. For rainfall, however, it is not necessary to do this at times when no firing is going on in Nevada and the Nevada test tropospheric material has been removed from the atmosphere. So, the data which are of principal use in measuring the total integrated fallout, are the foreign-soil samples. This does not mean to say that the soil data in the United States should not correlate with the rain-fallout data and, in fact they do, as figure 14 shows, which presents the complete series of Pittsburgh rainfall data, together with the U.S. average soil data as a function of time together with the theoretical for the overlap of the two bands at 30° to 40° from the U.S. tests in Nevada and 50° to 60° from the Russian midlatitude test site.

However, to check the theory carefully, it is necessary to choose foreign-soil samples which are widely selected over the world and which are carefully analyzed by the HCl extraction technique which removes all of the contained strontium 90. The only complete series of data available is for samples collected in the year 1956. They are presented in figure 15 together with the theoretical predicted curve for that same period. The total observed fallout was 8 megatons of fission and the 10-year residence-time theory would predict somewhat less than that, perhaps the average of 5.3 and 8.1 megatons, these being the figures for the two dates, January 1, 1956, and January 1, 1957. The foreign-soil samples were collected throughout 1956 and represent something like an

average for that period of time. Corresponding figures for the shorter stratospheric residence time of 5 years are 8.08 and 12.44. It would seem from these numbers that a residence time in the stratosphere of between 5 and 10 years is indicated. We shall see later that this agrees with other information as well. A series of soil samples taken in the spring of 1955 and 1956, together with some samples taken in the spring of 1958, for which preliminary analyses are available are presented in table IV. Focusing on the latitudes in the Southern Hemisphere so that tropospheric fallout will be minimal and taking the spring 1956 data we obtain an average of 2.8 millicuries per square mile at that time. Doing the same thing for 1958 we obtain 6.5 millicuries per square mile for a difference of 3.7 millicuries per square mile or an average fallout rate of 1.8 millicuries per square mile per year. Taking the mean stratospheric inventory from figure 6 for the year 1957 of about 24 megatons or 12 millicuries per square mile we calculate the stratospheric residence time which agrees with this. The result is 6.5 years which number will obviously agree well with the data shown in figure 15.

The difference between the United States and foreign collections in the given latitude is well illustrated by the monthly rain data for July, August, and September 1957 (4). The average of U.S. stations for those 3 months was  $2.4 \pm .25$  millicuries per square mile while the average for foreign stations in the same latitude was  $1.3 \pm 0.2$ , again agreeing with the soil data shown in table III. It is to be hoped that we will soon have analyses of the 1958 soil collections because it is clear that these data are of extreme importance in deciding about the mechanism of stratospheric fallout.

The Ascan project, the project for sampling the stratosphere by means of balloons and filters continues but analytical difficulties have cast some doubt on the validity of the data. It is to be recalled that a rough average figure for the stratospheric inventory samples is 50 disintegrations per minute per 1,000 standard cubic feet of air, and various evidence indicates that the filter efficiency may be 25 percent. Taking these rough numbers one then would deduce that the strontium 90 content of the stratosphere averages about 200 disintegrations per minute per 1,000 standard cubic feet in the early part of 1958 and late 1957. This number agrees very well with the theoretically calculated stratospheric inventory given in figure 6. Turning now, again, to the surface air concentration data taken by the Naval Research Laboratory and quoted earlier in table I which gave a mean surface concentration of about 0.3 disintegrations per minute per 1,000 cubic feet we make a direct comparison between the observed mean residence time of about 3 days and the stratospheric time. Multiplying 3 days by the ratio of 200 to 0.3 the mean value at the surface gives the stratospheric residence time. This result is 3 years, somewhat lower than the two previous values.

Taking all of these different lines of evidence into account and noting the general agreement with observation, we conclude that the simple model proposed earlier still is likely to be correct in many respects. To recount, it says that material introduced into the stratosphere is mixed rapidly vertically and horizontally and leaks down uniformly over the world at a rate of about 16 percent per year (this would correspond to a mean residence time of 6 years) into the troposphere where it is removed in about 1 month by normal weather processes and by impinging on the surface of trees, grass, and other features of the earth. Its main time is spent in the top 30,000 feet of the troposphere for it spends only about 3 days on the average in the bottom 10,000 feet. In this lower layer the possibility of being brought down by rainfall and surface impact is at a maximum. We have considerable evidence which is in the formative stages and we can expect that during the next weeks and months, the particular type of measurements displayed in table II which bear on the fate of the Russian October 1958 debris will be most revealing. These data, together with measurements on the rhodium 102 should very nearly settle most of the major points about the stratospheric mixing mechanism.

### III. THE ASSIMILATION INTO THE BIOSPHERE

The great question arises as to whether and at what rate the fallout is taken into the biosphere. During Operation Hardtack, a considerable effort was made to introduce tonnages of silica sand into firing barges on the thought that strontium 90 might thus be incorporated into glass-type insoluble beads which would thus be of reduced solubility and the probability of its being assimilated by plants and animals would thus be reduced. Measurements are now

being made on the fallout with this point in mind but of course it is extremely difficult to distinguish the Hardtack fallout, particularly if the author's simple model is correct, from the previous earlier shots, many of which were done in coral sand or in plain sea water and which have no insoluble components. It does indicate, however, the type of effort that might be made to reduce the assimilability of strontium 90 in the biosphere. Such an approach seems reasonable from a consideration of the nature of the fireball and the probable chemical processes occurring there.

Direct study of the assimilation of radioactive fallout into the human body is restricted very largely to a few isotopes, particularly strontium 90, cesium 137, and iodine 131. Cesium 137 has been studied particularly carefully by Langham and Anderson at the Los Alamos Scientific Laboratory 8, 9, 12, 14, 30) and figure 16 presents their data for the cesium 137 content of people in the United States in the year 1957 versus the milk content. It clearly shows that milk is not the only source of cesium as one would expect, a part of it comes from meat and vegetables even though milk is a major source. This figure shows also that the discrimination factor for cesium, relative to potassium in the milk, is about twofold, in contrast to the behavior of strontium relative to calcium in milk (1, 4, 5, 7, 11, 13).

They found, however, that the human content of cesium 137 did not rise appreciably from the value of  $41 \pm 1.3$  microcuries per gram of potassium in 1956 to the 1957 value of  $44 \pm 1.1$ . This small change, together with the fact that cesium is an isotope which should come into rapid equilibrium with the human body because its mean residence time is only some 120 days as compared to many years for strontium 90 indicates that the human body is very nearly in equilibrium with the food chain. First, the fact that there was no large rise between 1956 and 1957, together with the fact that certain observations on the strontium 90 content of milk and cheese over the years indicates that they too do not rise as rapidly as the total fallout observed in the soil, suggests that possibly a large part of the fallout which enters the biosphere does so by virtue of the pickup directly on the leaves of grass and vegetables which are eaten directly, either by cows or by people with the result that an entirely different approach to the question of the fallout hazard is made. Of course, it is absolutely certain that there is pickup of the radioactive fallout through the roots of plants. What may be the situation, however, is that this pickup is not nearly so serious as we have been supposing and a good part of the pickup we have observed has come from the leaves. If the latter is true then in a period of minimum fallout, the milk level and the vegetable level will fall correspondingly to a value somewhat closer to the amount that would come solely from the root pickup, and we would expect, therefore, that the steady state concentration in the human body of the fallout isotopes would be considerably lower than we have been calculating in the past. It is not clear at this time as to whether this conclusion is justified but further observation and study will make it clear and we should be alert to the importance and likelihood of this development.

### IV. CONCLUSION

The future course of the fallout investigation is well set and is now proceeding on an international scale so that within doubt the major questions about the fallout mechanism will be answered within the foreseeable future. Remaining, however, will be the tremendous problems of the biological consequences of fallout radiation. We shall make no attempt here to consider these. It is, however, an area of uncertainty so large that only the most conservative treatment of the permissible body burdens of fallout isotopes is tolerable and this conservative treatment indicates that care and caution must be taken about the matter of additional radioactive contamination. The U.S. Atomic Energy Commission has consistently tried to reduce the magnitude of the fallout from atomic testing and it is clear that the new technique of testing underground can further greatly reduce worldwide fallout. It is to be hoped that other nations will adopt this procedure, even though it is sometimes difficult and more trouble. It does have one advantage, however, in addition to eliminating fallout; it makes the test schedule independent of weather. With further development of procedures it ought to be possible to obtain most of the results on weapons design with this technique. Of course, the proof testing of weapons in their carriers might not be possible underground but the critical question of whether the warheads operate and give the yields and behave as they should, can be answered

by this method which is fallout free. No one who has studied radioactive fallout has any desire to unnecessarily increase the amount of it in anyway, but it is a risk and hazard which is limited and which can be considered relative to the advantages gained. It is necessary to watch it and to control it as carefully as possible.

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- (21) "Evaluation of the Ground Level Sampling Program." Machta, L. Paper presented at meeting of participants in fallout meeting held by AEC in Washington, D.C., December 5, 1958.
- (22) "Atmospheric Aspects of Strontium 90 Fallout." Martell, E. A., Cambridge Research Center. Science (in press). Dr. Martell suggests that the increases in rate of fallout which have occurred in the spring of each of the last several years are due to largely Russian tests of intermediate and high yield weapons which have injected debris into the lower and intermediate levels of the stratosphere and for which the debris exhibits relatively short residence times of the order of 6 months. He mentions that the stratospheric data are so uncertain it is unwise to use them yet and points out that the latitudinal profile for tropospheric fallout is probably considerably wider than corresponds to a 10° step function.
- (23) "World-Wide Effects of Atomic Weapons, Project Sunshine." Aug. 6, 1953, R-251-AEC (amended). It was this study conducted at the Rand Corp. in Santa Monica, Calif., in the summer of 1953 which launched the Sunshine project on radioactive fallout.
- (24) "Radioactive Strontium Fallout." Libby, W. F., proceedings of the National Academy of Sciences, vol. 42, No. 6, pp. 365-300, June 1956.
- (25) "Current Research Findings on Radioactive Fallout." Libby, W. F., proceedings of the National Academy of Sciences, vol. 42, No. 12, pp. 945-962, December 1956.
- (26) "Radioactive Fallout." Libby, W. F., proceedings of the National Academy of Sciences, vol. 43, No. 8, pp. 758-775, August 1957.
- (27) "Radioactive Fallout." Libby, W. F., proceedings of the National Academy of Sciences, vol. 44, No. 8, pp. 800-820, August 1958.
- (28) "Rain Scavenging of Radioactive Particulate Matter From the Atmosphere." Greenfield, S. M., Journal of Meteorology, 14, No. 2, pp. 115-125, April 1955.
- (29) "Daily Record of Fission Product and Activity Collected By Air Filtration." Lockhardt, L. B., Jr., Naval Research Laboratory, Washington, D.C.
- (30) "Cesium 137 Contamination from Nuclear Weapons Tests." Langham, Wright; Anderson, E. C. Health Physics (in press).

TABLE I

A. DEPOSITION FROM TROPOSPHERIC FALLOUT  
FROM SURFACE AIR FILTER DATA

| DATE        | Fission Product<br>Data* | Strontium-90<br>Data |
|-------------|--------------------------|----------------------|
| <u>1957</u> |                          |                      |
| July        | .07 Mt                   | .09 MT               |
| August      | .06                      | .08                  |
| September   | .13                      | --                   |
| October     | .11                      | .14                  |
| November    | .05                      | .07                  |
| December    | .05                      | .09                  |
| <u>1958</u> |                          |                      |
| January     | .07                      | .13                  |
| February    | .07                      | .18                  |
| March       | .10                      | .23                  |
| April       | .32                      | .15                  |
| May         | .16                      | --                   |
| June        | .16                      | --                   |
| July        | .13 (S)                  | --                   |
|             | .12 (N)                  | --                   |
| August      | .10 (N)                  | --                   |
|             | .08 (S)                  | --                   |
| September   | .06 (N)                  | --                   |
|             | .04 (S)                  | --                   |

Filter Efficiency 100% (Assumed)

Lower 10,000 feet (40% of the atmosphere) 3 day residence time

Troposphere (80% of the atmosphere) 30 day residence time

\* (20 KT = 25 dpm/CuM at equator)

(S) Southern Hemisphere

(N) Northern Hemisphere

TABLE I (CONT'D.)

## B. THEORETICAL TOTAL TROPOSPHERIC FALLOUT (MT)

| 1957  |     |     |     |     |     |     |     |     |     |     |     | 1958 |     |     |     |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|
| Month | J   | A   | S   | O   | N   | D   | J   | F   | M   | A   | M   | J    | J   | A   | S   |
| Theo. | .19 | .19 | .26 | .17 | .08 | .03 | .02 | .01 | .29 | .14 | .10 | .38  | .81 | .44 | .45 |
| Obs.  | .08 | .07 | .13 | .12 | .06 | .07 | .10 | .12 | .21 | .23 | .16 | .16  | .25 | .18 | .10 |

TABLE II

## 1959 FALLOUT DATA AND THEIR SIGNIFICANCE FOR STRATOSPHERIC FALLOUT MODELS

## A. Polar Fallout Theory 22/

For shots at or near the Poles, the stratospheric fallout occurs more rapidly than for shots elsewhere, especially the equatorial region for which a longer residence time of perhaps 5 to 10 years is appropriate.

Assuming  $\tau = 1$  year for northern latitudes, the present fallout rate on Dr. Martell's theory should be 32 to 33 mc/mi<sup>2</sup>/year.

The Sr<sup>89</sup>/Sr<sup>90</sup> ratios should be 115 for November  
77 for December  
51 for January  
32 for February.

## B. Uniform World-Wide Theory

Every addition is assumed to be mixed instantaneously and uniformly to all latitudes, longitudes, and altitudes. Then since the October additions amounted to a major increase, the fallout rates expected might be 1.6 times the previous values or 2.6 mc/mi<sup>2</sup>/yr for a 10 year residence time and 5.1 mc/mi<sup>2</sup>/yr for 5 years.

The Sr<sup>89</sup>/Sr<sup>90</sup> ratios expected would be 51 for November  
36 for December  
26 for January  
18 for February

## C. Experimental Data for Pittsburgh

## I. Pittsburgh rain data for November (Nuclear Science and Engineering Corporation)

TABLE II (CONT'D)

| Date              | Rainfall (inches) | Sr <sup>90</sup> Fallout mc/mi <sup>2</sup> | Sr <sup>89</sup> /Sr <sup>90</sup> |
|-------------------|-------------------|---------------------------------------------|------------------------------------|
| Oct. 28 to Nov. 2 | 0.02              | .020                                        | 33                                 |
| Nov. 2 to 3       | .31               | .084                                        | 62                                 |
| Nov. 3 to 6       | .02               | .004                                        | 57                                 |
| Nov. 6 to 9       | .13               | .073                                        | 43                                 |
| Nov. 9 to 10      | .30               | .070                                        | 46                                 |
| Nov. 10 to 15     | .25               | .103                                        | 35                                 |
| Nov. 15 to 16     | --                | .013                                        | 29                                 |
| Nov. 16 to 17     | .03               | .013                                        | 48                                 |
| Nov. 17 to 18     | .04               | .020                                        | 44                                 |
| Nov. 18 to 19     | .19               | .059                                        | 48                                 |
| Nov. 19 to 24     | .02               | .044                                        | 27                                 |
| Nov. 24 to 26     | .02               | .030                                        | 28                                 |
| Nov. 26 to 29     | .19               | .079                                        | 42                                 |
| Total             | 2.21              | .632                                        |                                    |

Versus 2.7 from Polar theory and .42 from uniform theory with  $\tau = 5$ .

## D. Experimental data for Westwood, New Jersey for December (Isotopes, Inc.)

| Date               | Rainfall (inches) | Sr <sup>90</sup> Fallout (mc/mi <sup>2</sup> ) | Sr <sup>89</sup> /Sr <sup>90</sup> |
|--------------------|-------------------|------------------------------------------------|------------------------------------|
| Nov. 19 to Nov. 26 | 0.12              | .129                                           | 32                                 |
| Nov. 26 to Dec. 1  | 2.30              | .542                                           | 35                                 |
| Dec. 1 to Dec. 4   | 0.58              | .153                                           | 34                                 |
| Dec. 4 to Dec. 8   | 0.16              | .091                                           | 35                                 |
| Dec. 8 to Dec. 10  | 0.20              | .080                                           | 37                                 |
| Dec. 10 to Dec. 15 | 0.02              | .035                                           | 32                                 |
| Dec. 15 to Dec. 23 | Dry               | <.002                                          | --                                 |
| Dec. 23 to Dec. 30 | 0.22              | .107                                           | 33                                 |
| Total              | 3.70              | 1.139                                          |                                    |

Strontium-90 fallout is approximately 1.00 mc/mi<sup>2</sup>/month versus 2.7 expected by Martell or 0.4 expected by uniform theory.

(more)

TABLE II (CONT'D)

E. Experimental data for Washington, D. C. for January 1959 (author)

| <u>Date</u>   | <u>Rainfall (inches)</u> | <u>Sr<sup>90</sup>Fallout(mc/m<sup>2</sup>)</u> | <u>Sr<sup>89</sup>/Sr<sup>90</sup></u> |
|---------------|--------------------------|-------------------------------------------------|----------------------------------------|
| Jan 1         | 1.84                     | .350                                            | 23 ± 3                                 |
| Jan. 14 to 15 | 0.17                     | .098                                            | 29 ± 1                                 |

F. Comparison with previous years

|                                                        |                            |
|--------------------------------------------------------|----------------------------|
| Pittsburgh - Average rate for last year                | 1.00 mc/m <sup>2</sup> /mo |
| Pittsburgh - Average rate for 1955-1956                | .80 mc/m <sup>2</sup> /mo  |
| Pittsburgh - Average rate for Nov. Jan. in 1955 - 1957 | .24 mc/m <sup>2</sup> /mo  |

(more)

TABLE III

U. S. AND FOREIGN SOIL Sr<sup>90</sup> CONTENT

1956

|                              | <u>Zone</u> | <u>mc/m<sup>2</sup></u> |
|------------------------------|-------------|-------------------------|
| United States                | Average     | 17.7                    |
| Foreign                      | 20° - 30°N  | 5.6                     |
|                              | 30° - 40°N  | 6.3                     |
|                              | 40° - 50°N  | 7.1                     |
| Average                      | 20° - 50°N  | 6.3                     |
| Difference (U. S. - Foreign) |             | 11.4                    |

This corresponds to 340 KT fallout versus a total of 688 KT fired of which 308 KT was estimated to be local.

(more)

TABLE IV

## A. SUMMARY SOIL DATA FOR FOREIGN SAMPLES

| Latitude        | Spring 1955 | Spring 1956 | Spring 1958 |
|-----------------|-------------|-------------|-------------|
| 90° S - 70°S    |             |             |             |
| 70° S - 60°S    |             |             |             |
| 60°S - 50°S     |             |             |             |
| 50°S - 40°S     | 1.8         | 2.5         | 8.6         |
| 40°S - 30°S     | 3.0         | 3.6         | 7.8         |
| 30° - 20°S      |             | 2.7         | 6.2         |
| 20° S - 10°S    |             |             |             |
| 10° S - Equator | 0.5         | 2.3         | 3.5         |
| Equator - 10°N  |             | 3.4         | 6.4         |
| 10° N - 20°N    | 1.2         | 6.3         | 6.4         |
| 20°N - 30°N     | 3           |             | 20          |
| 30° N - 40°N    | 4.3 ± 2.5   | 4.2         | 23 ± 4      |
| 40° N - 50°N    | 3.90 ± 2.0  |             |             |
| 50° N - 60°N    |             |             |             |
| 60° N - 70° N   |             |             |             |
| 70° N - 90°N    |             |             |             |

TABLE IV (CONT'D)

## B. Inferences from soil data

|                              |                               |
|------------------------------|-------------------------------|
| Southern Average Spring 1956 | - 2.8 mc/ml <sup>2</sup>      |
| Southern Average Spring 1958 | - 6.5                         |
| Difference                   | - 3.7                         |
| Average Fallout Rate         | - 1.85 mc/ml <sup>2</sup> /yr |
| Mean Stratospheric Inventory | - 12 mc/ml <sup>2</sup>       |
| Residence half time, $\tau$  | - 6.5 years                   |



# RADIOACTIVITY PROFILE - 1957 FISSION PRODUCTS

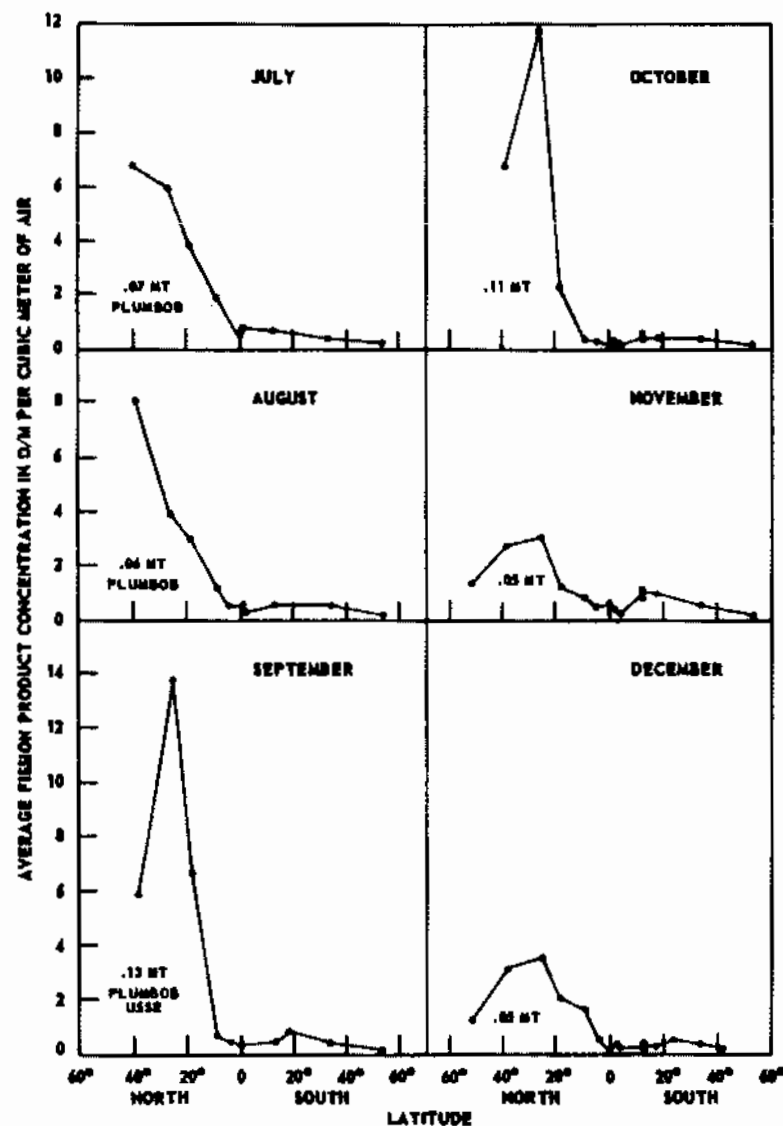


FIGURE 1

# RADIOACTIVITY PROFILE - 1958 FISSION PRODUCTS

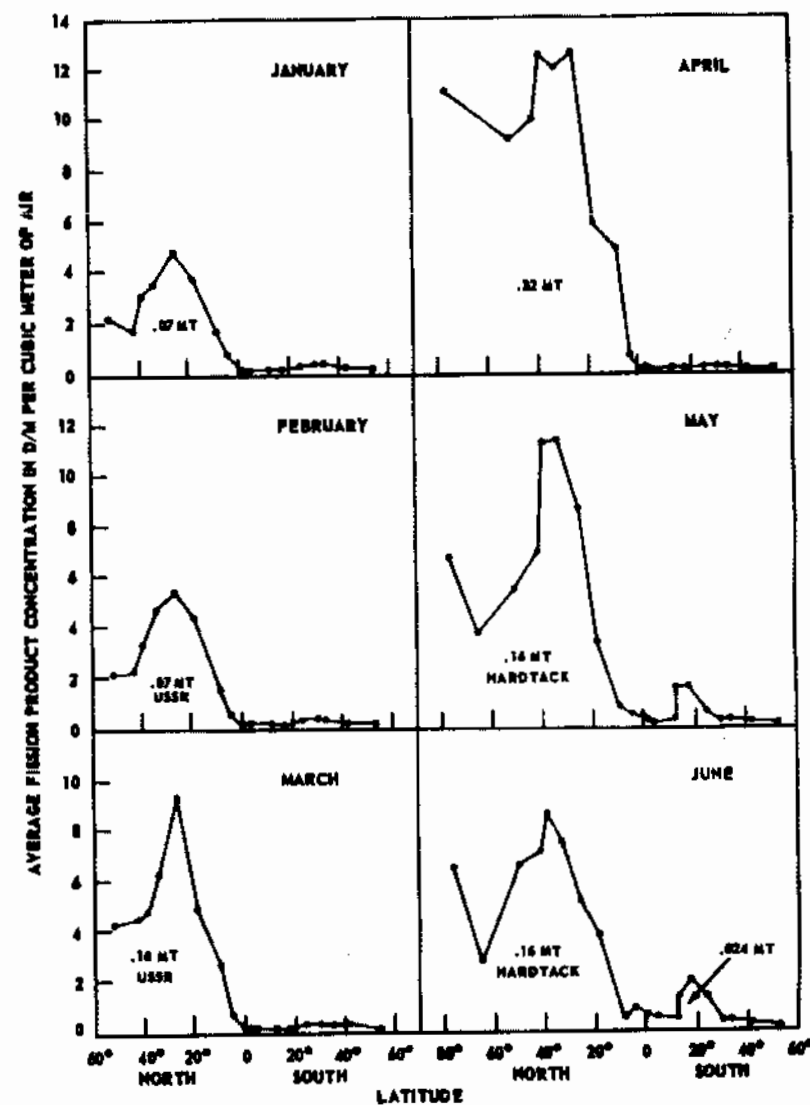


FIGURE 2

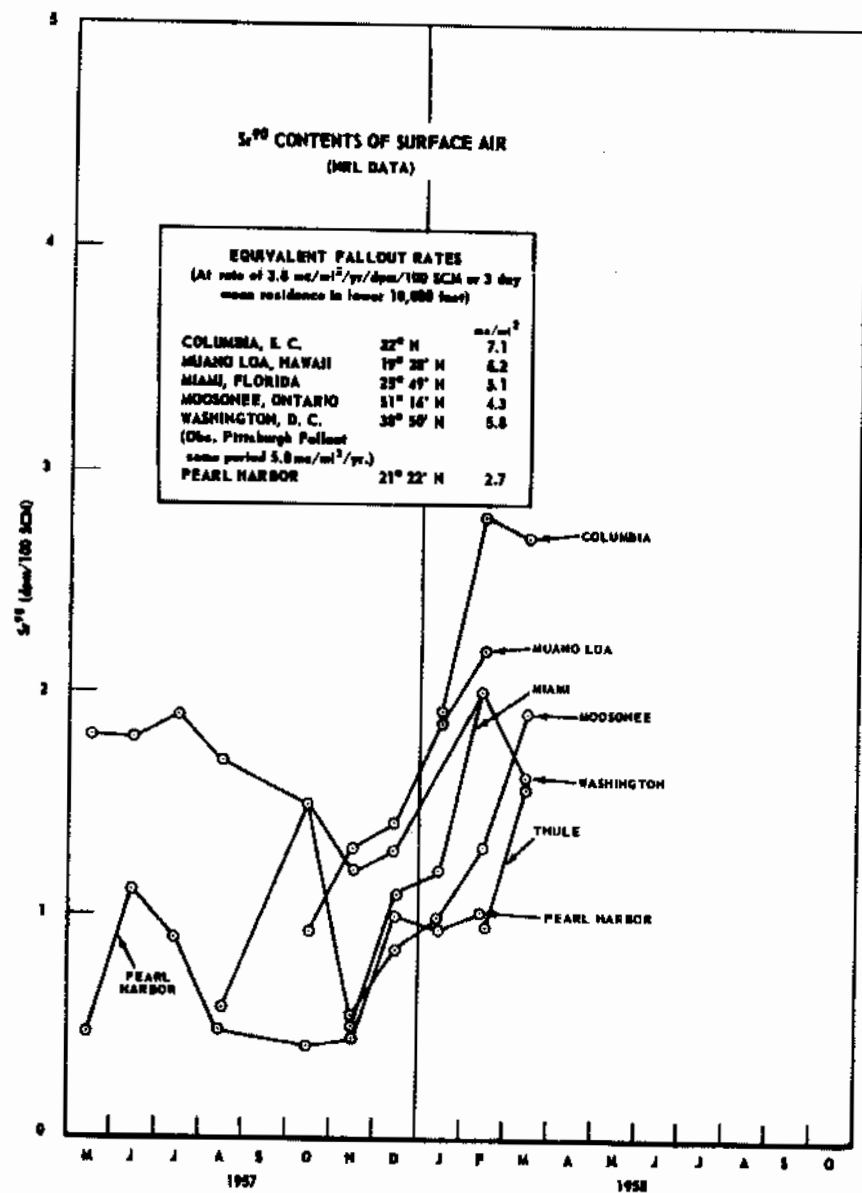


FIGURE 3

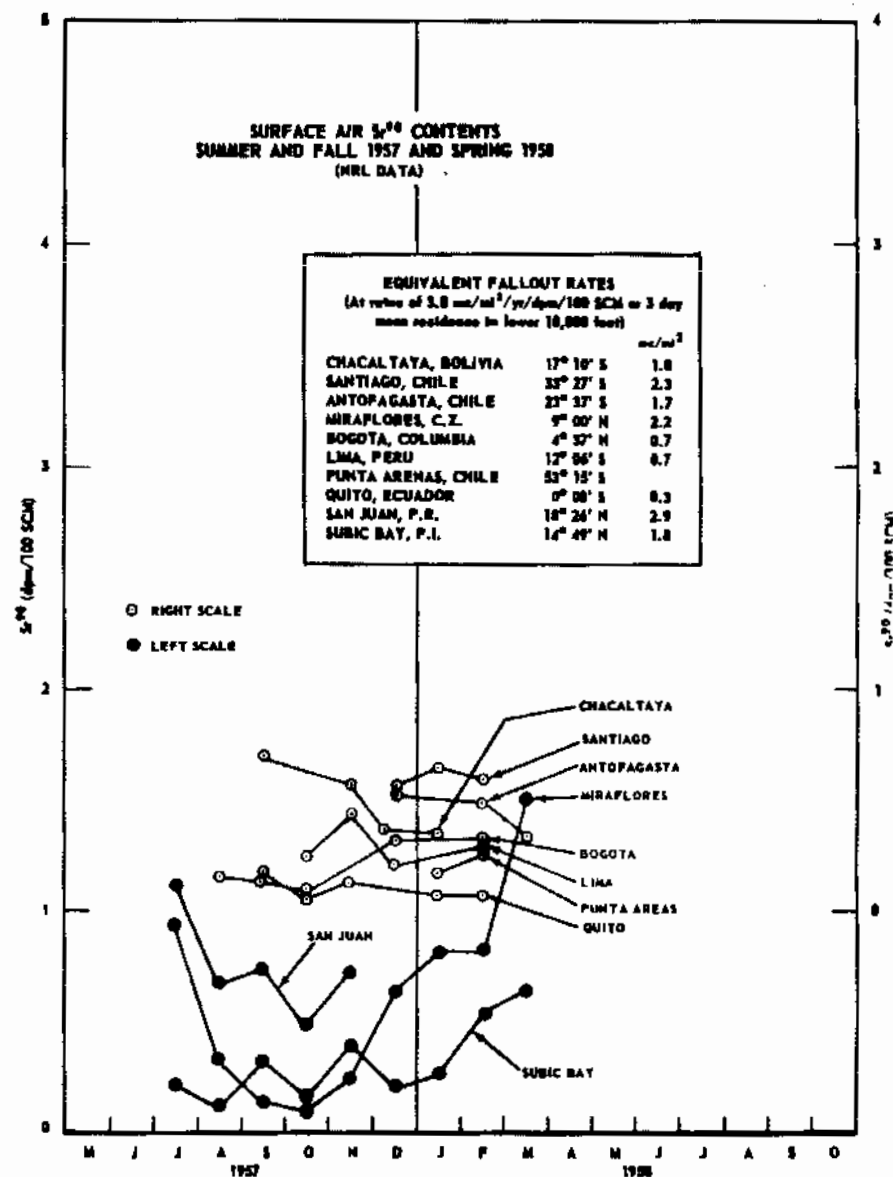


FIGURE 4

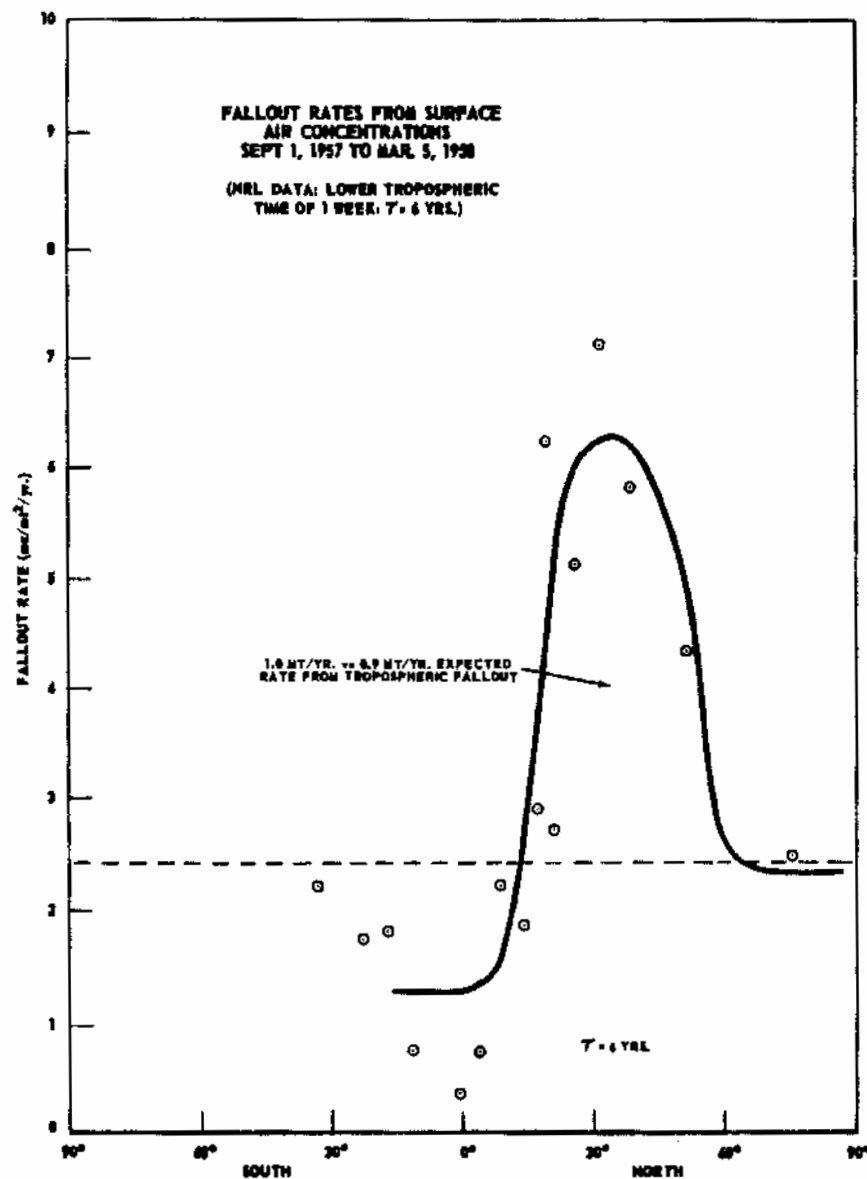
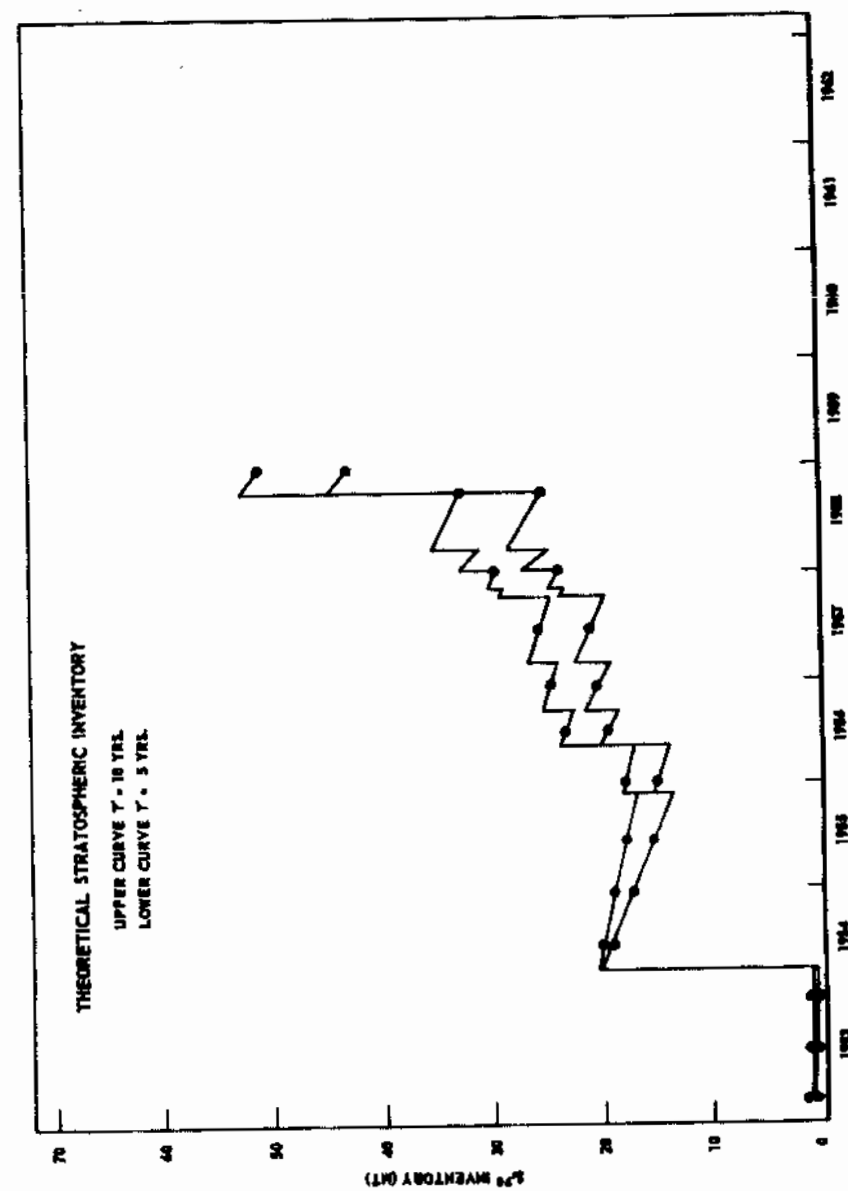


FIGURE 5



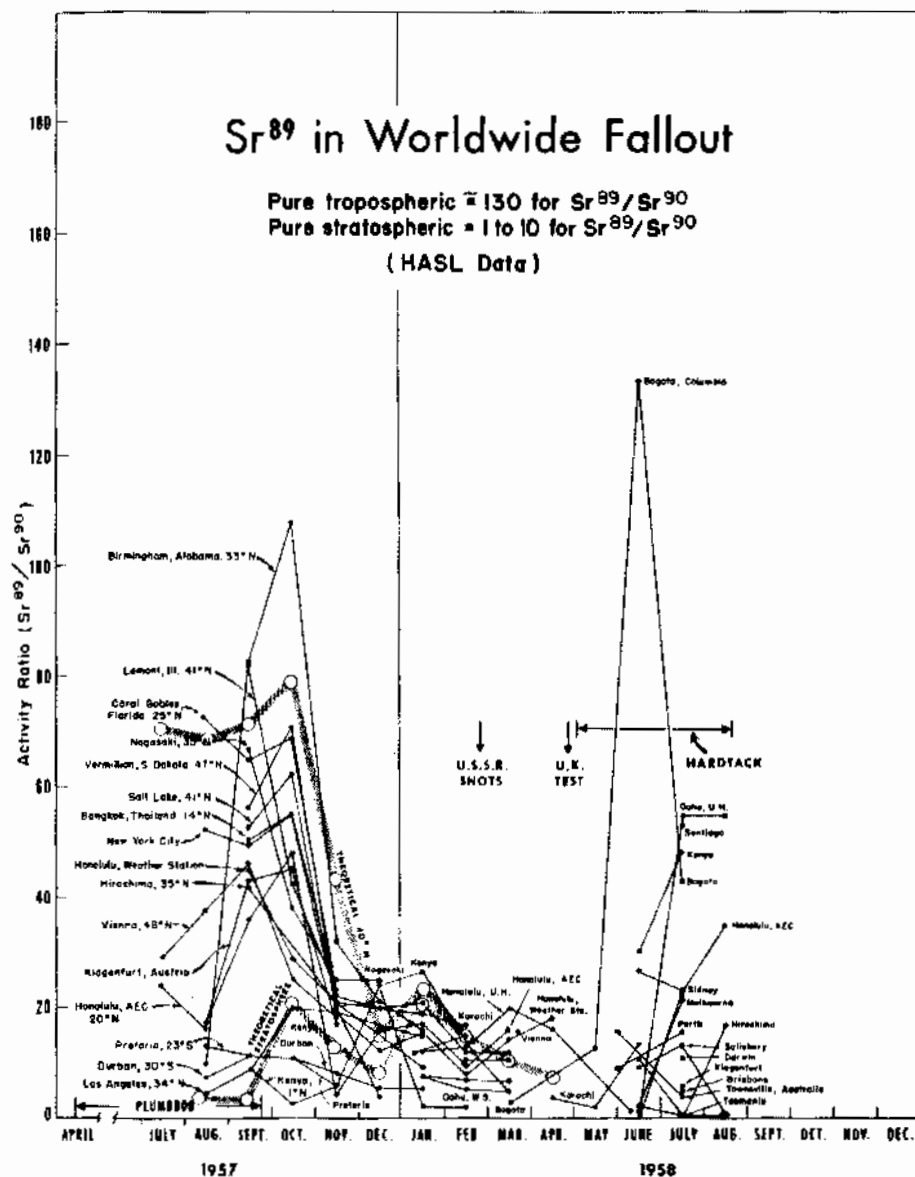


**FIGURE 7**

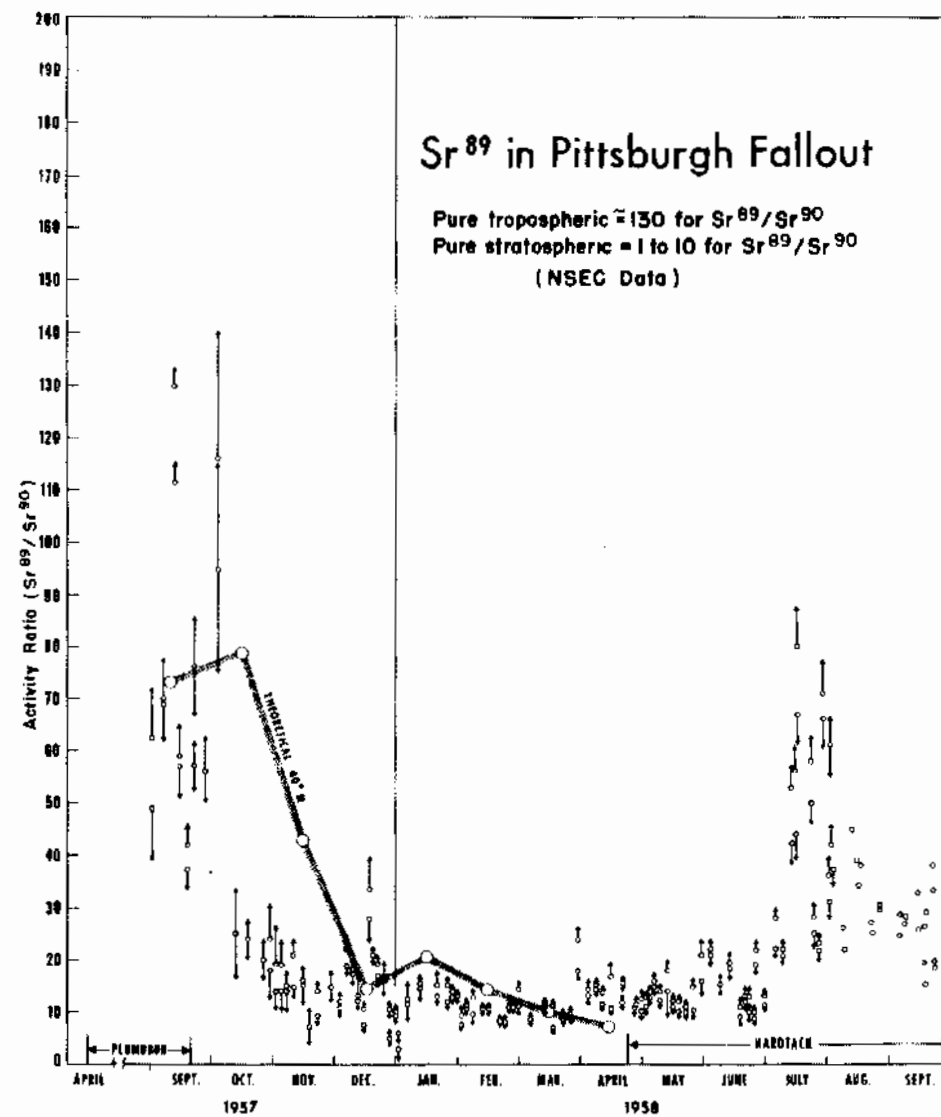


**FIGURE 8**

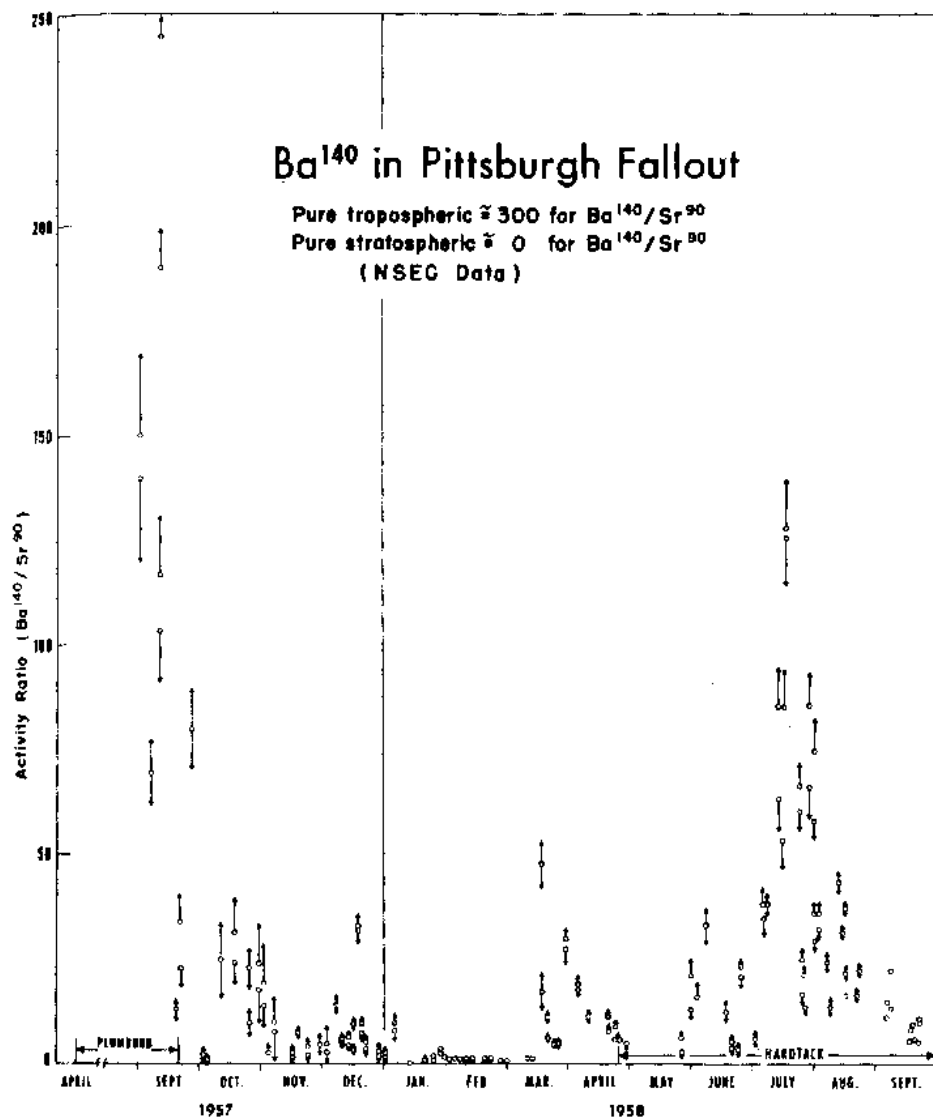


FIGURE 9

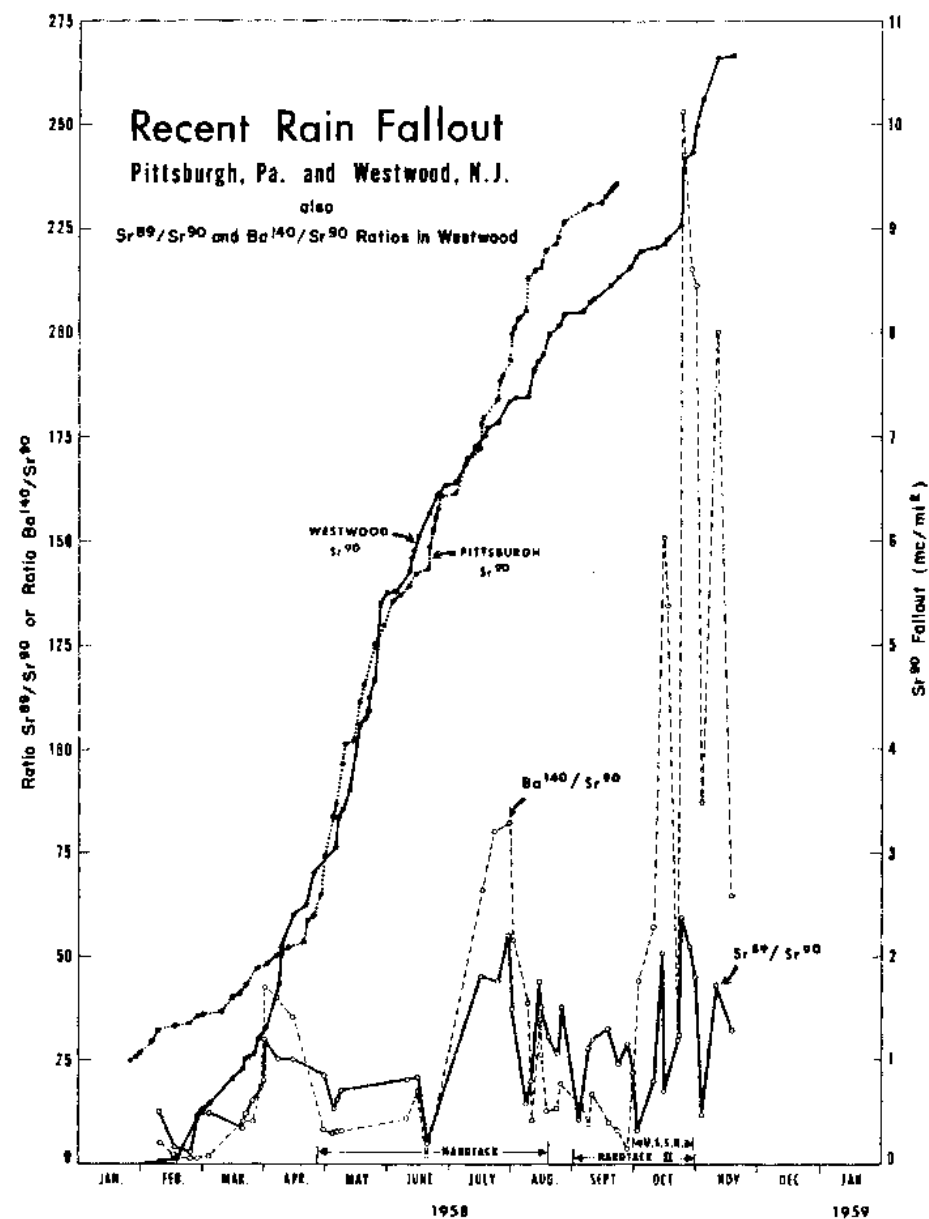


FIGURE 10

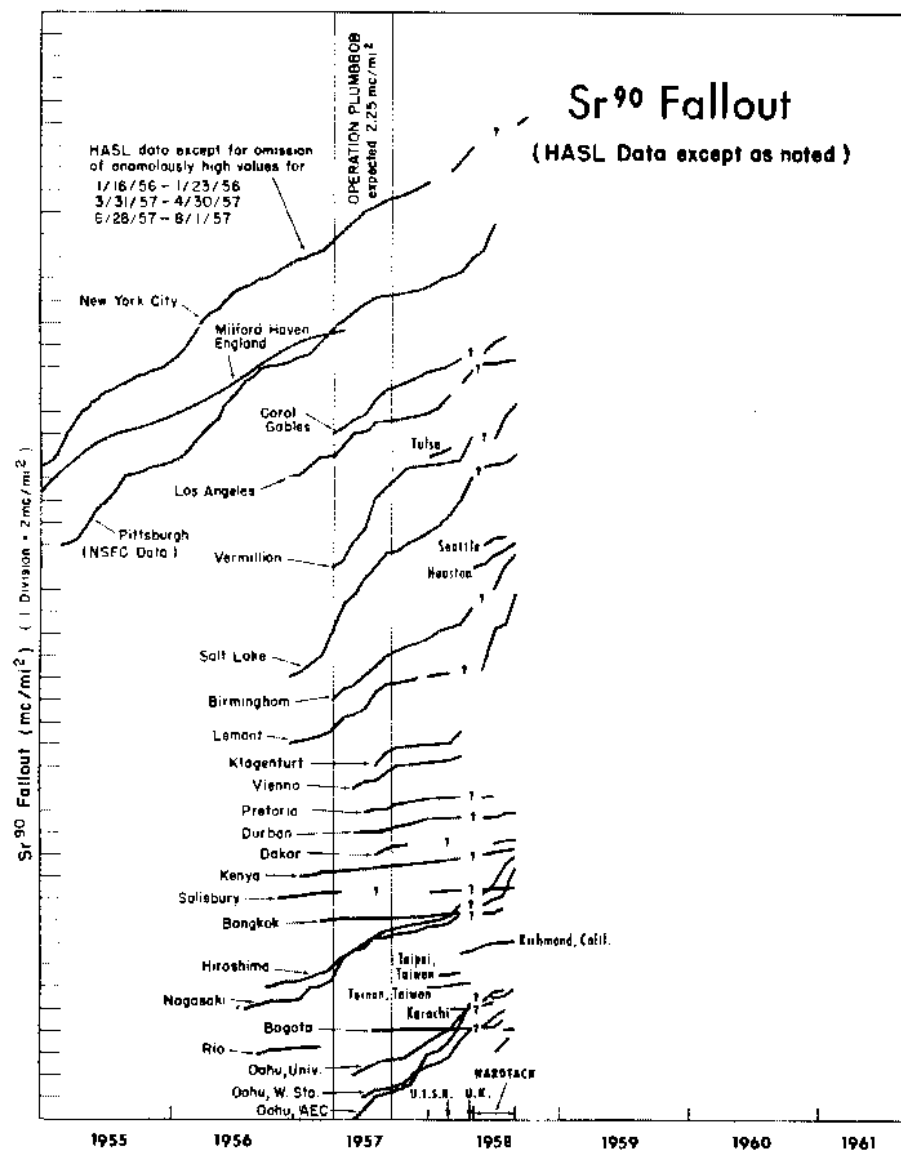


FIGURE 11

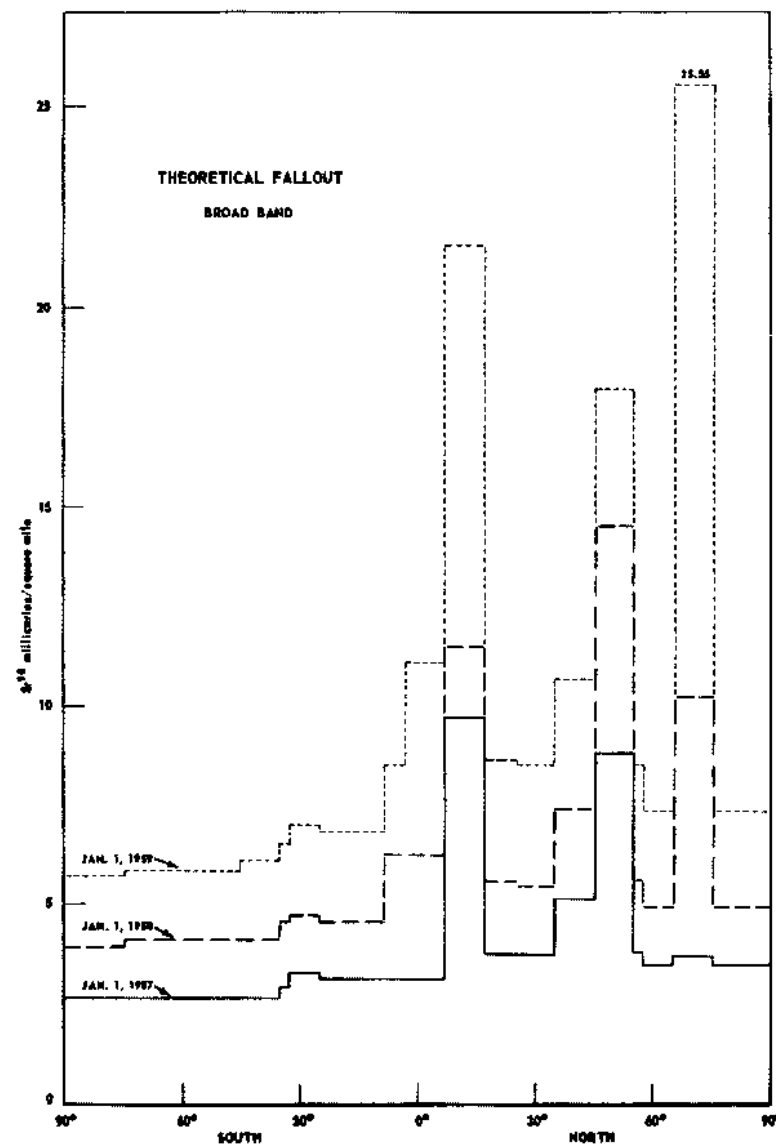


FIGURE 12

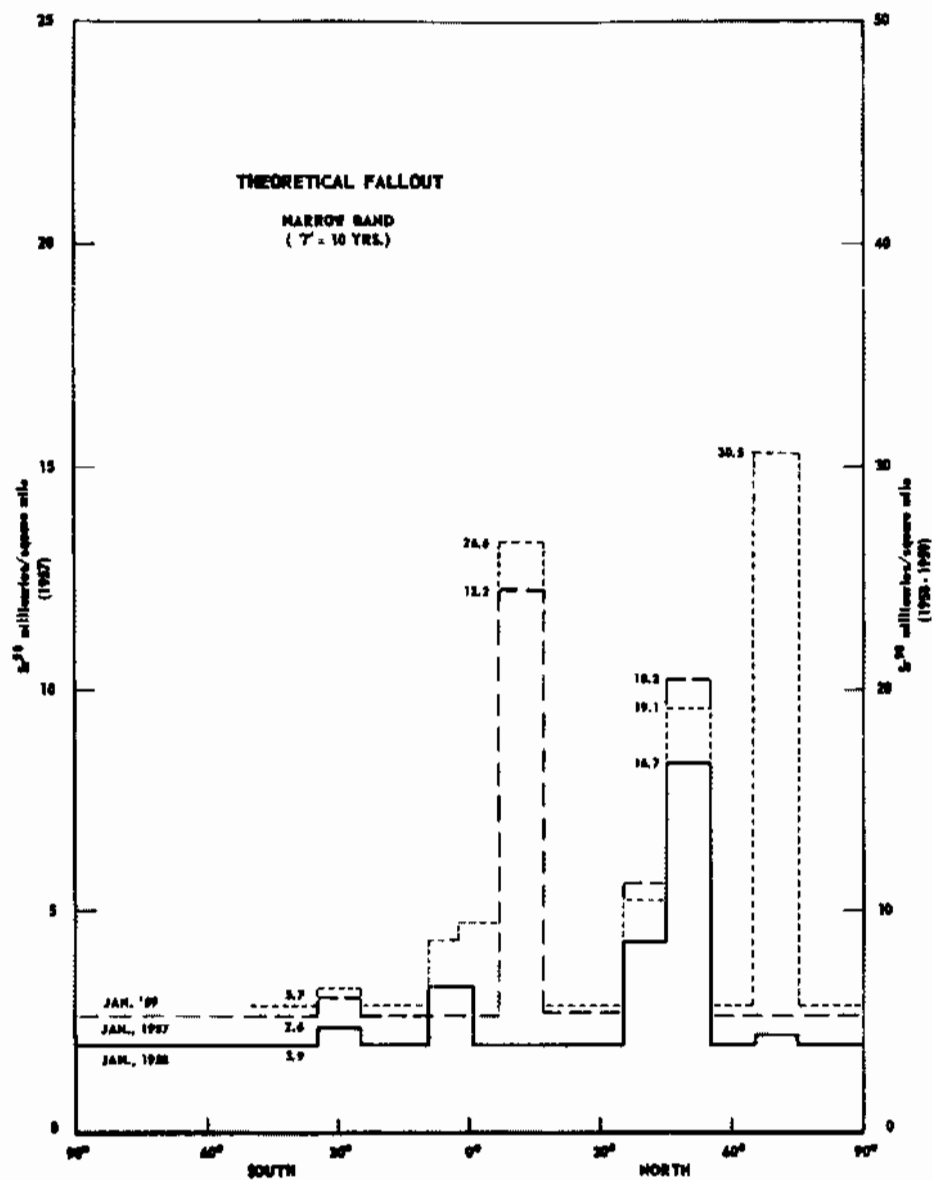
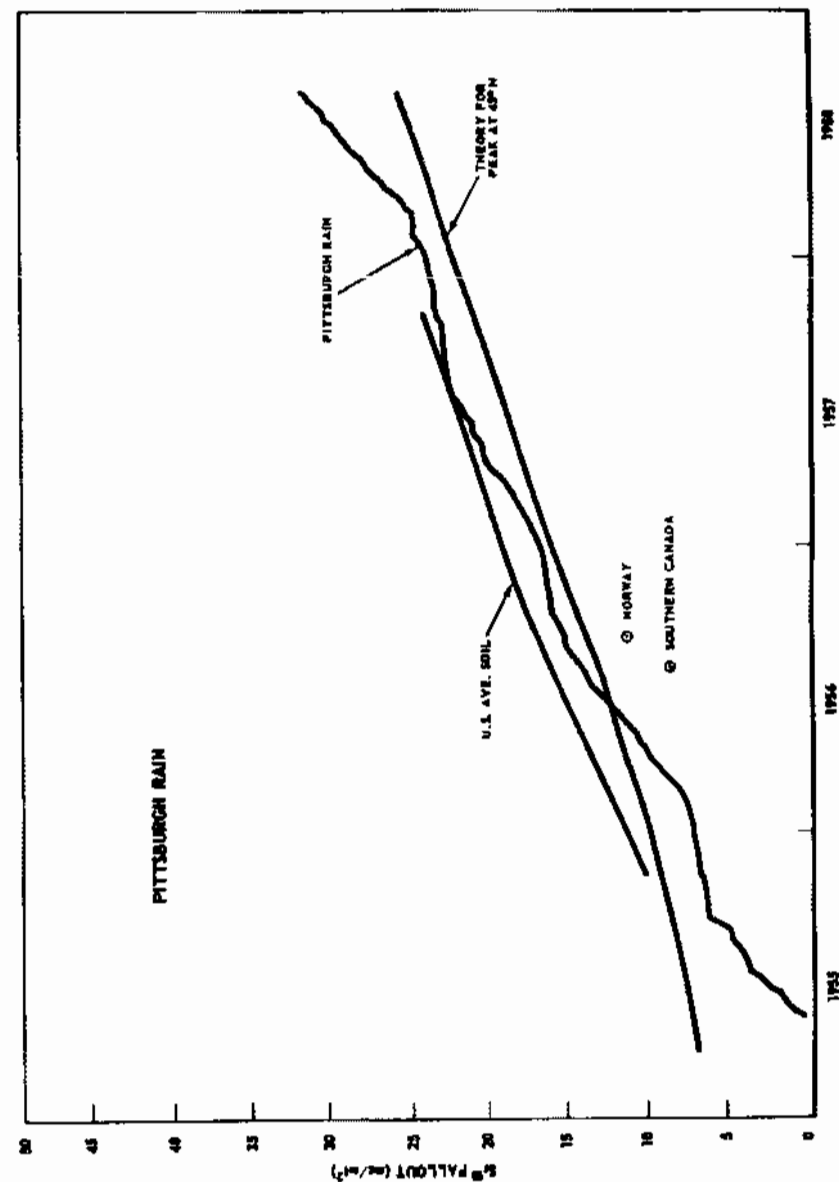


FIGURE 13



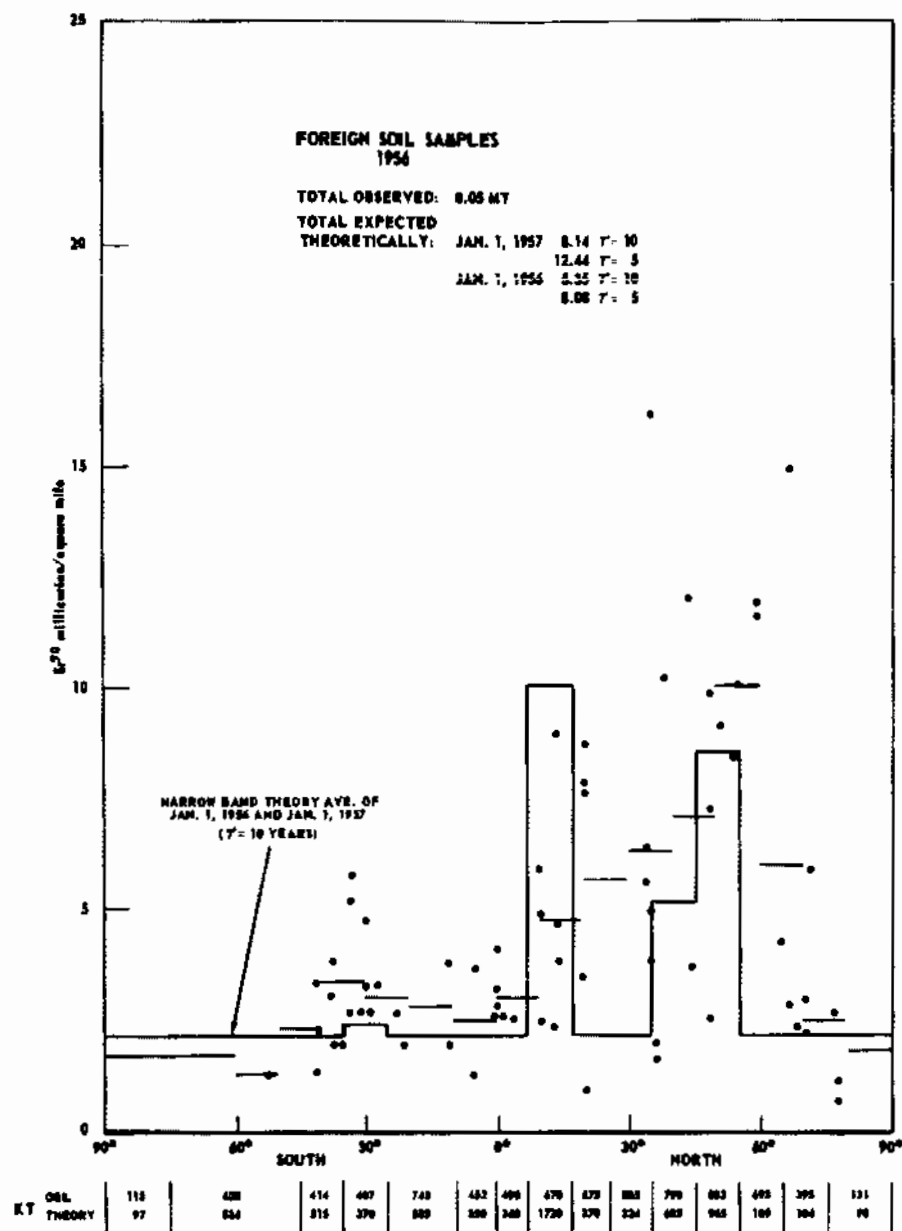


FIGURE 15

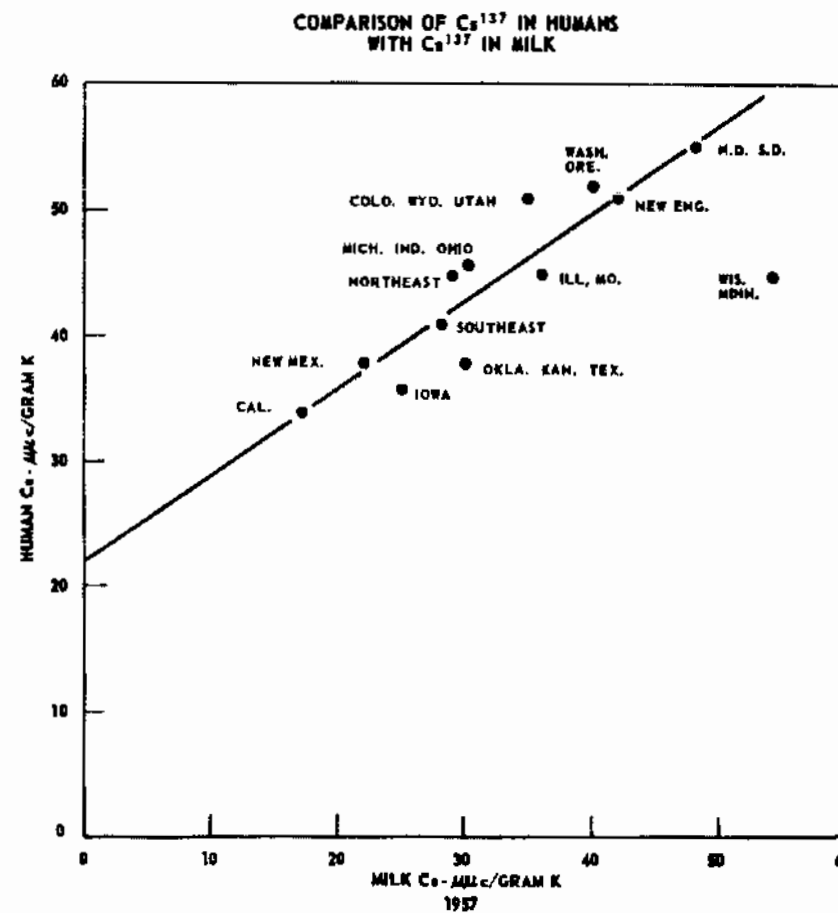


FIGURE 16



## APPENDIX D

## COMMENTS ON GENERAL ADVISORY COMMITTEE REPORT

ATOMIC ENERGY COMMISSION,  
Washington, D.C., May 5, 1959.

HON. CLINTON P. ANDERSON,  
Chairman, Joint Committee on Atomic Energy,  
Congress of the United States.

DEAR SENATOR ANDERSON: In my testimony before the Joint Committee on Atomic Energy on March 24, 1959, I stated I had requested Dr. Warren Johnson, Chairman of the Commission's General Advisory Committee, to call a special meeting of the Committee for the purpose of reviewing the matter of radioactive fallout and advising me of any additional steps the Commission might take to further protect the public interest.

I have now received the report of the General Advisory Committee and transmit a copy of it to you herewith. The report is being made public.<sup>1</sup>

Sincerely yours,

JOHN A. MCCONE,  
Chairman.

Enclosure: Report of GAC.<sup>1</sup>

CONGRESS OF THE UNITED STATES,  
JOINT COMMITTEE ON ATOMIC ENERGY,  
May 18, 1959.

MR. JOHN A. MCCONE,  
Chairman, U.S. Atomic Energy Commission,  
Washington, D.C.

DEAR MR. MCCONE: During the Special Subcommittee on Radiation's hearings on fallout, I raised some questions with the Commission's representative, Dr. Dunham, concerning the General Advisory Committee report on fallout which was released during the hearings. I regret that because of time difficulties I was not able to raise these questions with Dr. Libby for consideration by the seminar on implications of testing.

As requested during my discussion, I would appreciate it if the GAC would be requested to provide a more thorough and comprehensive review of the fallout problem, with particular reference to the factors and problems identified by the subcommittee in advance as of special interest. Copies of the subcommittee's outlines are attached for reference.

Of particular interest to the committee would be a more detailed explanation and evaluation by the General Advisory Committee of the problem of fallout from possible future tests conducted at the same rate as those which have been held by all nations for the past 5 years, up to the time of the test moratorium last fall. In that connection, the GAC might desire to review Dr. Langham's paper and testimony, and also the statement and testimony of the seminar and roundtable in the implications of testing.

It would also be helpful if the General Advisory Committee would consider the problem of area "hotspots" and their relationship to average figures and determination of permissible doses. The problem of short-lived isotopes also would appear to merit consideration.

I believe the above information would be of assistance in helping clarify the present picture with regard to problems associated with possible resumption of testing and would provide the committee with a better understanding of the exact position which the General Advisory Committee has taken on these matters.

Sincerely yours,

CLINTON P. ANDERSON, Chairman.

<sup>1</sup> See p. 1378 of hearings for text of GAC report, together with introductory letter to Chairman McCone from Warren Johnson, Chairman of the GAC.

ATOMIC ENERGY COMMISSION,  
Washington, D.C., August 27, 1959.

HON. CLINTON P. ANDERSON,  
Chairman, Joint Committee on Atomic Energy,  
Congress of the United States.

DEAR SENATOR ANDERSON: In your letter of May 18, 1959, you asked that the General Advisory Committee be requested to undertake a more thorough and comprehensive review of the fallout problem. Enclosed for your information are two letters, dated July 7 and July 30, 1959, respectively, from Dr. Warren C. Johnson, Chairman of the GAC, reporting on the suggestions made in your May 18 letter.

With respect to items A and B in the report contained in Dr. Johnson's letter (see p. 2263), the Commission has forwarded to the Committee additional data and the AEC staff comment on the "hotspots" on June 2 and again on July 24, 1959. This additional material is being provided to the GAC.

With respect to item C, we have reviewed the statement prepared by the panel of experts convened by the AEC at the request of Mr. Hollifield's Special Subcommittee on Radiation and believe the conclusions and predictions made by that highly qualified group to be sound.

With respect to item D, the report indicated that detailed appraisal of the biological and genetical effects of short-lived isotopes should be made by the Advisory Committee for Biology and Medicine. This matter will be discussed with the Advisory Committee for Biology and Medicine at its next scheduled meeting on September 18 and 19.

Sincerely yours,

JOHN A. MCCONE, Chairman.

GENERAL ADVISORY COMMITTEE TO THE  
U.S. ATOMIC ENERGY COMMISSION,  
Washington, D.C., July 7, 1959.

MR. JOHN A. MCCONE,  
Chairman, U.S. Atomic Energy Commission,  
Washington, D.C.

DEAR MR. MCCONE: In my letter of May 21 addressed to you it was stated that an attempt would be made to prepare a reply to the questions raised by Senator Clinton P. Anderson in his letter of May 18, 1959. Senator Anderson also referred to "factors and problems identified by the subcommittee (JCAE) in advance as of special interest."

Some of the questions implied by Senator Anderson are readily answerable and demand only statements of fact and do not require additional discussion within the full membership of the General Advisory Committee. These statements are as follows:

(1) The GAC in preparing its statement of May 4 did not attempt to assess the biological and medical effects of radiation resulting from fallout and other sources. This was primarily because we felt that such assessment should properly be made by biologists, radiologists, and geneticists. The May 4 statement merely summarizes the data on the amount of fallout and the extent of radiation from both fallout and natural sources without endeavoring to appraise the biological and medical effects.

(2) The GAC does not have among its membership anyone who is expert in the field of biology, medicine, or radiology. In the briefings presented to the Committee, advice in these fields was obtained from the following experts:

- Dr. Charles L. Dunham, Director, Division of Biology and Medicine, U.S. Atomic Energy Commission.
- Dr. Lauriston S. Taylor, Chairman of the National Committee on Radiation Protection and Management.
- Dr. Shields Warren, U.S. Representative to the United Nations Radiation Committee and former Director of the Division of Biology and Medicine, U.S. Atomic Energy Commission.
- Dr. John C. Bugher, former Director of the Division of Biology and Medicine, U.S. Atomic Energy Commission; Vice Chairman of the Advisory Committee for Biology and Medicine, U.S. Atomic Energy Commission.

Dr. Simeon Cantril, Chairman of the Advisory Committee for Biology and Medicine, U.S. Atomic Energy Commission.

Dr. Leroy E. Burney, Surgeon General, Public Health Service.

Dr. Francis J. Weber and Mr. James G. Terrill, Chief and Assistant Chief, respectively, of the Division of Radiological Health, Public Health Service.

(3) Other individuals who met with the Committee for discussion of the general problem were:

Dr. Lester Machta, Chief of the Special Projects Section, U.S. Weather Bureau.  
Hon. Arthur S. Flemming, Secretary of Health, Education, and Welfare.

Adm. Edward N. Parker, Chief, Armed Forces Special Weapons Project, Department of Defense.

Dr. Frank Shelton, Technical Director of AFSWP, Department of Defense and other personnel from AFSWP.

(4) The GAC has followed closely for a number of years the problems presented by fallout. The Committee has been presented with reports and briefings periodically and it has taken a great interest in the problems. It should be emphasized that the early recognition by the Commission of the possible future hazards attending fallout was very helpful to the Committee in developing a knowledgeable status.

Accordingly, at the time the GAC received your request on March 23 to meet in special session for the purpose of reviewing (1) the problems presented by radioactive fallout, and (2) the activities of the Commission as well as those of reevaluating the earlier data. In accomplishing this assignment, the full Committee was already quite knowledgeable and its task was then primarily one of assessing the new information that was rapidly becoming available and of re-evaluating the earlier data. In accomplishing this assignment, the full Committee, with the exception of one member, met in Washington on April 9-11. Further discussions were held on April 28 and they included three members of the Committee, the Director of the Division of Biology and Medicine, and the Chairman of the Advisory Committee on Biology and Medicine. During the period of April 11-May 4, considerable time was spent by the members of the GAC in the preparation of a statement; following several successive drafts, the final statement was formulated on May 4 when the full Committee was again in session. We consider that we gave the matter the time and attention required by your terms of reference and much more than the 3 days referred to.

(5) In the preparation of the statement, issued May 4, the Committee made no attempt to study the question of future fallout and its attendant effects in the event that testing should be continued at some assumed level. The Committee did not regard this particular problem to be within the terms of reference of its assignment, nor do we think anyone seriously proposes that testing should be continued at the same rate as for the 5 years immediately prior to the test moratorium.

• It is now evident that it will not be possible to call another special session of the GAC before its regular meeting at Hanford scheduled for July 20-22. However, at the Hanford meeting I shall present to the full Committee the question of the desirability of expanding our statement of May 4 to include the following items:

(a) The extent of nonuniformity of distribution of fallout resulting in "hot spots."

(b) The evaluation of new data and information on fallout acquired during the past 6 months.

(c) The evaluation of the problems created by fallout in the event testing were to be continued at the same rate as that of the 5 years immediately prior to the test moratorium of last fall. Here it is to be assumed that the rate of testing means the same amount of fissionable material injected into the atmosphere.

(d) An evaluation of the effects of other radioactive isotopes in addition to strontium 90.

Any statements that the committee may formulate at the Hanford meeting in July will be transmitted to you promptly.

Sincerely,

WARREN C. JOHNSON, *Chairman.*

GENERAL ADVISORY COMMITTEE  
TO THE U.S. ATOMIC ENERGY COMMISSION,  
Washington, D.C., July 30, 1959.

Mr. JOHN A. McCONE,  
*Chairman, U.S. Atomic Energy Commission,*  
Washington, D.C.

DEAR MR. McCONE: In my letter to you of July 7, I summarized certain facts with regard to the General Advisory Committee's consideration of the fallout problem and its report thereon. I also indicated that the committee, at its forthcoming meeting at Hanford, would consider the desirability of expanding its statement of May 4 to cover the following items raised by Senator Anderson's letter.

(A) The extent of nonuniformity of distribution of fallout resulting in "hot spots."

(B) The evaluation of new data and information on fallout acquired during the past 6 months.

(C) The evaluation of the problems created by fallout in the event testing were to be continued at the same rate as that of the 5 years immediately prior to the test moratorium of last fall. Here it is to be assumed that the rate of testing means the same amount of fissionable material injected into the atmosphere.

(D) An evaluation of the effects of other radioactive isotopes in addition to strontium 90.

The committee did consider the four above-mentioned points at its Hanford meeting (July 20-22) and reports as follows:

(A) The committee was well aware of the nonuniformity of fallout and commented on it, but did not think it appropriate to include a detailed discussion of this in its general survey and appraisal of the fallout problem. It recognized that public authorities must be on the lookout for unusual local situations, but does not regard as serious any of the local situations which have occurred to date. It must be recognized that the "permissible limits" which are set for foodstuffs, such as milk or flour, are based on the presumption of continued use for a long period and that exceeding these limits moderately for a short time need be no cause for alarm.

(B) The new data and information on fallout for the past 6 months is now in process of compilation. As soon as it is available, we will review it with interest, especially since it took place during a period when, so far as we know, there was no weapons testing. If it changes any of our opinions or conclusions, we will advise you promptly.

(C) As to the evaluation of the problems created by fallout in the event testing were to be continued at the same rate as that of the 5 years immediately prior to the test moratorium, we see no useful purpose to be served by such a study, as no one is seriously proposing that testing be resumed at anything like that rate. We would also need to know at what locations the tests were to be made and what kind of tests.

(D) As to an evaluation of the effects of other radioactive isotopes in addition to strontium 90, we did not ignore the existence of such substances in drafting our report, but we feel that a detailed appraisal of the biological and genetic effects of the various other isotopes should be made by the Advisory Committee on Biology and Medicine.

Very truly yours,

WARREN C. JOHNSON, *Chairman.*

CONGRESS OF THE UNITED STATES,  
JOINT COMMITTEE ON ATOMIC ENERGY,  
September 14, 1959.

HON. JOHN A. McCONE,  
*Chairman, Atomic Energy Commission,*  
Washington, D.C.

DEAR MR. McCONE: This is with reference to your letter of August 27 enclosing GAC replies to my request of May 18.

I regret that it took so long to obtain these replies, especially since the pending adjournment makes it difficult to point out the inadequacies of the GAC letters in detail.

I would particularly take exception to the GAC statement in its July 30 letter as follows:

"(C) As to the evaluation of the problems created by fallout in the event testing were to be continued at the same rate as that of the 5 years immediately prior to the test moratorium, we see no useful purpose to be served by such a study, as no one is seriously proposing that testing be resumed at anything like that rate. We would also need to know at what locations the tests were to be made and what kind of tests."

It would appear that the GAC is making policy judgments, rather than answering technical questions which seem to me to be reasonable and appropriate. Certainly the Defense Department and the AEC seem to believe that additional testing may be necessary. France does also. The U.S.S.R. may also join in.

In conclusion, I would like to reiterate the requests I made in my May 18 letter, and especially invite the GAC to take into account the complete data contained in our hearings. This would include the panel to which you refer and Dr. Langham's paper.

Sincerely yours,

CLINTON P. ANDERSON.

A COMMENTARY UPON THE MAY 4, 1959, REPORT OF THE GENERAL ADVISORY COMMITTEE<sup>1</sup>

(By Ralph E. Lapp, July 7, 1959)

When a group of eminent science advisers appointed by the President to give counsel to the Atomic Energy Commission issues a report on radiation hazards, their statement deserves careful appraisal. The GAC through its chairman, Dr. Warren C. Johnson, made its first public report available to the AEC late on May 4, 1959, in response to a request from Mr. John A. McCone.<sup>2</sup> The next day, at a luncheon address before the National Press Club in Washington, D.C., the AEC Chairman stated that the GAC report "will give further reassurance to the people of the world about the very small hazard resulting from fallout."

The GAC report has subsequently made public on May 7, 1959, during a session of the Hollifield hearings on radioactive fallout. It received the greatest play in the press of any development during the investigation; for example, the GAC report was reproduced in full text in the New York Times with a story lead: "AEC Study Belittles Fallout; Advisers Report Radiation Low."

Current membership of the General Advisory Committee consists of physical scientists<sup>3</sup> whereas the subject evaluated is the biological hazard of nuclear radiation. Their lack of authority in the biological and medical field should have impressed upon the committee members the necessity for substantiating their conclusions; yet their report bears no literature citations or other documentation. Instead of presenting numerical or semiquantitative estimates of the radiation hazard, the committee members gave highly qualitative opinions.

The heart of the GAC report centers in sections (5) and (6) in which the genetic and somatic effects of nuclear radiation are evaluated in two sentences.

Section (5) states:

"It is interesting to note that human beings have lived for many generations in parts of the world which have five times or more the background normal to the United States or more than 100 times the average amount of radiation from fallout in the United States."

This is, of course, interesting, but what does it prove? Although the GAC report does not identify the regions of interest, it is a fact that the advisory committee consulted with Dr. Shields Warren and judging from the following quotation<sup>4</sup> the reference implied is to the Kerala region in India:

"Dr. Shields Warren pointed out in testimony that in India a large population has lived for many centuries in a monazite rock area where the background

<sup>1</sup> Prepared for publication in Bulletin of Atomic Scientists.

<sup>2</sup> In a statement made public on Mar. 24, 1959, Mr. McCone revealed that he had called a special meeting of the GAC for Apr. 9-10 to review the significance of nuclear radiation hazards from weapons tests.

<sup>3</sup> Quoted from AEC press release of Mr. McCone's speech of May 5, 1959.

<sup>4</sup> "American Men of Science" lists the eight committee members and consultant as follows: Two physicists, two physical chemists, two chemists, one chemical engineer, one electrical engineer, and one petroleum engineer.

<sup>5</sup> "Summary Analysis of Hearings May 27-29 and June 3-7, 1957, on the Nature of Radioactive Fallout and Its Effects on Man," Joint Committee on Atomic Energy Print, p. 4, August 1957.

levels are 5 to 20 times the average natural background. According to testimony, while the effects have not been obvious enough to cause the population to abandon the region, one cannot say what the effects have been until careful studies are made."

To date no such studies on the biological effect of this abnormally high background radiation have been made. Scientists associated with the United Nations are studying the problem and so far have gathered the physical data about the radioactivity in the Kerala region. The 1958 report of the United Nations Scientific Committee on the Effects of Atomic Radiation tabulates<sup>5</sup> radiation exposure data for 10 sites in the Kerala region applicable to a total population of 52,000 people. As pointed out by Dr. Karl Z. Morgan:<sup>6</sup> "There is always a probable error associated with a biological or physical measurement and at very low dose rates, i.e., background levels, it requires observations on an extremely large number of animals (or men) in order that the probable errors become less than the magnitude of the effects under observation or in this case to prove that there is any danger or in fact any detectable effect of exposure at the background level."

It may be possible to demonstrate radiation effects in the Kerala population, but it will require careful investigation, patient accumulation of the statistical data and critical evaluation of the statistics. So far as the GAC statement is concerned, the important thing is that the appropriate studies have not been concluded—they are hardly begun—and it is most unscientific to pass judgment prior to the receipt of the data.

Section (6) of the GAC report deals with the controversial problem of the somatic effects of strontium 90. It is quoted in full:

"In regard to the internal effects of strontium 90 due to ingestion, the amount of strontium 90 which has been found in food and water is less of a hazard than the amount of radium normally present in public drinking water supply in certain places in the United States, and in public use for many decades."

The validity of this assertion presupposes that the radium hazard in public water source has been evaluated and is known to be negligible from the viewpoint of a public health hazard used as a criterion for evaluating the global fallout problem.

What are the facts supporting the GAC statement on strontium 90? There is a distressing lack of documentation or technical reference so that in order to probe into the generalized assertion, one has to formulate the following series of questions:

- (1) Where are the unnamed water supplies containing radium?
- (2) What is their radium content?
- (3) How large a population do these water sources serve?
- (4) To what extent does the affected population take up radium?
- (5) What statistically significant biomedical data have been found for this population?

The writer has attempted to supply answers to these questions by a literature search, by inquiry and by analysis. The following information has been developed:

(1) *U.S. water supplies containing unusual radium concentrations.*—A number of U.S. communities derive their water supply from deep wells known to contain above average amounts of radium.<sup>7</sup> The largest U.S. population affected concentrates in the Middle West, principally in Illinois, Iowa, and Wisconsin.

(2) *Radium content of these water sources.*—The concentration of radium in 150 municipal water supplies in Illinois has been measured by H. F. Lucas, Jr., and F. H. Ilicewicz<sup>8</sup> who find above normal amounts of radium in water drawn from deep sandstone wells; the concentrations ranging from 1 to 25 microcuries per liter ( $\mu\text{Ci/l}$ ). In some communities the tapwater may exhibit lower concentrations due to filtration, iron removal, water softening or possibly by selective uptake of radium in the distribution system.

<sup>5</sup> Table XVII, p. 55 of United Nations Document 17 (A/3888), August 1958.

<sup>6</sup> "Maximum Permissible Exposure of the Population-at-Large to Sources of Ionizing Radiation," Statement given to the special Subcommittee on Radiation, Joint Committee on Atomic Energy, May 7, 1959.

<sup>7</sup> J. B. Hursh, "The Radium Content of Public Water Supplies," University of Rochester publication UR-257 (1953).

<sup>8</sup> "Natural Radium 22 Content of Illinois Water Supplies," Journal American Water Works Association, vol. 50, p. 1523 (November 1958).

Handbook No. 69 of the National Bureau of Standards<sup>10</sup> lists the maximum permissible concentration (MPC) at  $Ra^{226}$  in water for occupational exposure as  $4 \times 10^{-7} \mu\text{c/cc}$ . This corresponds to a value of  $40 \mu\text{c/l}$ . We are concerned with a general population as contrasted to an occupational group and must therefore consider the "mpc" for the former. The International Commission on Radiological Protection (ICRP) recommends that "for planning purposes" the mpc be taken as one-thirtieth the MPC. Using this reduction factor of 30, the radium 226 mpc in water becomes  $1.3 \mu\text{c/l}$ .

(3) *Illinois population using deep sandstone well water.*—The Argonne National Laboratory is conducting a survey of the population served by well water showing a high radium content. The following data<sup>11</sup> are representative as of May 13, 1959: 126,000 people use drinking water with radium content in the 3 to  $4 \mu\text{c/l}$  range, 259,000 people have water supplies above the  $4 \mu\text{c/l}$  mark and 274,000 people are not classified as yet.

(4) *Bone retention of radium occurring in well water.*—The experimental findings of A. F. Stehney and H. F. Lucas<sup>12</sup> on radium uptake show that boys living in Lockport, Ill., where they are exposed to a concentration of  $8 \mu\text{c/l}$  in the public water supply exhibit a mean body burden of 370  $\mu\text{c}$  of radium. Chicago youths exposed to Lake Michigan water with a radium content of 0.03  $\mu\text{c/l}$  have a tenfold lower body burden. Food in the Chicago area contributes a total of about 1.6  $\mu\text{c}$  to the daily diet. Thus if one assumes a daily intake of 2.5 liters of water, the Chicago youths receive more radium in food than in lake water, whereas the Lockport boys get much more radium from their water supply. Dr. L. D. Marinelli of the Argonne National Laboratory has summarized<sup>13</sup> the skeletal burden of radium to be expected in adult populations drinking 2.5 liters per day.

(5) *Bone tumor deaths in Illinois.*—We come now to the problem of correlating exposure to unusual amounts of radium in the water supply with injurious effects in the exposed population. Dr. H. Auerbach of the Argonne National Laboratory is making a detailed analysis<sup>14</sup> of the average mortality from bone cancer in the State of Illinois for an 11-year period ending 1950. Data have been accumulated on 2,294 bone tumor deaths in 88 million man-years at risk, but it is understood that the analysis of these data does not yet permit positive correlation between increased incidence of bone cancer with geographic localities where the radium content of public drinking water is abnormally high. Something of the difficulty of the analysis may be appreciated by noting that the bone tumor death rate is highly age specific and may be as low as 0.32 per 100,000 persons per year.

In making a comparison between two radiation hazards—radium in drinking water and strontium 90 as a biospheric contaminant—it must be recognized that there are differences to be taken into account. For example, infants are not water drinkers in their early life. If we consider the cow as the dietary source, it is exposed to the pasture contamination of strontium 90 but not to radium from deep well water to the same degree. If we neglect such factors, we may compare the skeletal radiation dosages that the Lockport boys may expect from fallout and from radium taken up from water. Let us assume that a Lockport boy has a body burden of 400  $\mu\text{c}$  at age 20 and maintains this level throughout an additional 50 years of life.<sup>15</sup> Their radiation dose<sup>16</sup> will be of

<sup>10</sup> "Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational," recommendations of the National Committee on Radiation Protection issued June 5, 1959.

<sup>11</sup> The writer follows the custom of using MPC to denote the occupational level and the lower case mpc to designate the level for a general population.

<sup>12</sup> The writer is indebted to Dr. Charles L. Dunham of the AEC for this information.

<sup>13</sup> "Studies on the Radium Content of Humans Arising From the Natural Radium of Their Environment" in the proceedings of the International Conference on the Peaceful Uses of Atomic Energy, vol. 11, p. 49 (1956).

<sup>14</sup> "Radioactivity and the Human Skeleton," Amer. J. Roentgen and Radium Therapy, vol. LXXX, p. 732 (November 1958).

<sup>15</sup> Reported in "Geographic Studies in Bone Tumors," by H. Auerbach in the July-December 1957 semiannual report of the Division of Biology and Medicine of the Argonne National Laboratory, report ANL-5841.

<sup>16</sup> This is not inconsistent with data on the uptake of radium in adult prisoners admitted to the Stateville Penitentiary (Joliet, Ill.), where the local water supply assays 3.4  $\mu\text{c/l}$ .

<sup>17</sup> Data are derived from table 1 of Dr. W. B. Looney's article, "Effects of Radium in Man," Science, vol. 127, p. 631 (1958). Data given in reference (12) indicates a slow buildup of radium in adults; this is assumed to add 0.4 rad to the 50-year dose.

the order of 1 rad. If one uses the equivalence that  $100 \mu\text{c}=12 \text{ mrad/yr}$ , the dose is 2.5 r. There is an uncertainty about the RBE value to apply to radium as well as a nonuniformity of radium deposition within the bone.

A body burden of 10 strontium units will produce a 70-year dose of about 2 rads. This is close to the average to be expected in northern United States by 1965. A log-normal distribution of strontium 90 in bone will result in a significant fraction of the young population accumulating 4 times this average or 40 S.U. corresponding to a lifetime radiation dose of 8 rads. This is roughly the radiation dose to which human bone is exposed over a lifetime of irradiation by the natural background.

If one accepts the information presented above—and since it is both quantitative and documented, it is subject to acceptance or rejection—it would appear that the statement on radiation hazards by the General Advisory Committee to the Atomic Energy Commission is misleading. And unless the GAC presents a technical justification for its statement, one is forced to conclude that this highly placed scientific body has either acted hastily or has received inadequate advice on the problem.

It is actually rather odd that the General Advisory Committee should have been consulted for its views on the biological hazard at this time. Throughout the peak of public interest in fallout during the past 5 years, the GAC made no public comment. However, the AEC's Advisory Committee for Biology and Medicine has twice reported<sup>18</sup> on the subject.

The public and the scientific community is due some explanation for the behavior of the General Advisory Committee in this instance and it is to be hoped that some further elucidation on this score will be forthcoming from the Atomic Energy Commission.

<sup>18</sup> The first report, "Genetic Considerations of Atomic Weapons Tests," dated May 12, 1955, was released on June 3, 1955, and the second report "Statement on Radioactive Fallout Submitted to the Commission" was dated Oct. 19, 1957.

## APPENDIX E

## MAXIMUM PERMISSIBLE LEVELS

[Extract from article by R. Björnerstedt and A. Engström in Science, Feb. 6, 1950<sup>1</sup>]

## MAXIMUM PERMISSIBLE BODY BURDEN OF STRONTIUM 90

**Abstract.**—The permissible body burden of  $\text{Sr}^{90}$  is discussed with respect to the mode of intake. It appears that the maximum permissible load may depend on the type of exposure, acute or chronic, the acute being the more serious.

The purpose of studying the distribution and metabolism of bone-seeking isotopes is to make it possible to derive the dose rates (local and average) to different parts of the skeletal tissue. In this way it may be possible in the end to establish values for the maximum permissible body burdens of various bone-seeking isotopes. This procedure includes a comparison of the derived dose rates with those judged to be necessary and sufficient for the production of various biological effects, such as malignant blood and bone changes. This seems at present to be a possible means of hazard evaluation when lack of data makes direct comparisons difficult between the body burdens of different isotopes and the resulting biological effects.

The foregoing argument is general in that it applies to most bone-seeking isotopes. A general treatment of the principles for dose-rate calculations for such isotopes has recently been given (1). Specific isotopes have, furthermore, been treated in several works. In the following discussion (2)  $\text{Sr}^{90}$  will be chosen to illustrate the method proposed for estimating maximum permissible body burdens.

It has been calculated (1) that the skeletal tissues receive a dose rate of 2.6 rem per year (or 7.25 mrem per day) on the average, from a total body burden of 1  $\mu\text{C}$  of homogeneously distributed  $\text{Sr}^{90}$ . This assumes a homogeneous dispersion of the  $\text{Sr}^{90}$  in the 7,000 g. of skeletal tissue (the standard man). A body burden of 1  $\mu\text{C}$  of  $\text{Sr}^{90}$  is equivalent to 1,000 S.U. (sunshine units, or  $\mu\text{C}$  of  $\text{Sr}^{90}$  per gram of Ca).

It is obvious from several investigations that the assumption of a homogeneous  $\text{Sr}^{90}$  distribution is unrealistic, since  $\text{Sr}^{90}$  occurs both as a general diffuse labeling and in localized sites (reactive bone) of microscopic and macroscopic dimensions. If the dose rates are calculated in relation to the isotopic content of the reactive bone sites, where a great deal of  $\text{Sr}^{90}$  is found, more realistic data may be attained. It is therefore necessary to consider the geometrical distribution of these reactive sites.

The geometrical configuration may be accounted for by two extreme cases, the cylindrical geometry of the Haversian systems and the more irregular appearance of the labeling in spongy bone. Estimates show that spongy bone is often the more important tissue when high dose rates are considered. However, it is an impossible task to make exact dose calculations for the spongy bone. A simplified geometry has to be assumed, and this has been done in a recent monograph (1) in which a system of plane parallel slabs of reactive bone interspersed with regions of bone marrow is considered. It is found that a homogeneous contamination of the reactive bone slabs with 1

$\mu\text{C}$  of  $\text{Sr}^{90}$  per gram of bone may give maximum dose rates of 25 to 85 mrem per day to bone and bone-marrow cells, with corresponding average values of 15 to 20 and 12 to 16 mrem per day. It is now important to remember that the reactive bone constitutes a certain fraction of the 7,000 g. of bone tissue that the standard man is supposed to contain. This fraction varies with the state of growth and remodeling of the bone tissue. It thus differs for children and adults as well as for different bones and parts thereof within the same skeleton. It appears legitimate to assume a fraction of around 0.20 to 0.25 to be a representative average figure. Thus, 1,400 to 1,750 g. of the skeleton is considered to be reactive. In adults it can be estimated that approximately half of the reactive bone is found as spongy bone where the major part of the blood-forming bone marrow is situated.

If the maximum permissible value of 1  $\mu\text{C}$  of  $\text{Sr}^{90}$  is considered, the following dose rates are obtained: 7,000 g. of bone will receive more than 1.8 mrem per day and, on the average, 5.5 mrem per day; 700 to 900 g. of spongy bone will, on the average, receive 10 mrem per day—in some parts, 21 mrem per day; 1,500 g. of red bone marrow will receive more than 1.8 mrem per day and, on the average, 7.5 mrem per day; 1,100 g. of red bone marrow will receive an average of 9 mrem per day—in some parts, 21 mrem per day.

The maximum-dose-rate values given above are based on one assumption which is obviously not fulfilled; namely, that of homogeneous labeling of the different reactive sites or "hot spots" in relation to each other. However, variations in the  $\text{Sr}^{90}$  concentrations are to be considered rather the rule than an exception. Regions of the same dimensions as the average range of  $\text{Y}^{90}$  beta particles ( $\sim 2$  mm.), and containing a large number of hot spots, may differ from the average in  $\text{Sr}^{90}$  concentration by a factor of 5 to 10. This implies a corresponding increase in the maximum dose rates to some parts of the bone tissue.

It should finally be pointed out that the simplified geometry used to depict the spongy bone may lead to dose-rate values that are too low in comparison with those for biological material. It is easy to conceive of geometrical arrangements (for example, bone lamellae meeting in a corner or inhomogeneous activity distribution within hot spots) which will give locally a twofold to threefold increase in the maximal dose rate. A body burden of 1  $\mu\text{C}$  of  $\text{Sr}^{90}$  acquired in one exposure may thus give dosage rates on the microscopic level as high as 300 to 500 mrem per day to certain parts of the reactive bone tissue and the bone marrow.

It seems advisable to correlate the permissible body burden with the maximum local dose rates rather than with the average whole-body values. The production of bone and blood malignancies is probably dependent on the local microscopic conditions; that is, on the local dose rates. Thus, when we compare the dose rate of 300 to 500 mrem per day from 1  $\mu\text{C}$  of  $\text{Sr}^{90}$  with the dose of 1,000 rem, which is considered after a relatively long period to be significant in the production of biological damage to bone tissue, it is apparent that this dose (1,000 rem) may be attained within 10 years. This suggests a revision of the value for the maximum permissible body burden of  $\text{Sr}^{90}$  to 0.1  $\mu\text{C}$  instead of the currently accepted value of 1  $\mu\text{C}$ , which was derived from comparison with radium data.

The foregoing argument is concerned with acute or short-time poisoning with  $\text{Sr}^{90}$ . If  $\text{Sr}^{90}$  is taken into the body over a considerable period, the situation is different, as the pattern of isotopic localization becomes different. Such "chronic poisoning" conditions prevail today for children born in recent years as essentially all calcium available in the biosphere is, and will be, contaminated with  $\text{Sr}^{90}$  from weapon tests.

If in the first instance considered above, a uniform contamination is assumed, 7,000 g. of bone will receive an average dose of 7.25 mrem per day. This dose rate is maximal to red bone marrow which on the average receives 1.5 mrem per day. The degree of mineralization varies, however, and it is found, on comparing regions of the same dimensions as the average beta range ( $\sim 2$  mm.) that there may be calcium concentrations which differ from the average by a factor of 2 to 3. This implies that certain parts of the bone and bone marrow may receive doses of around 15 mrem per day.

It is apparent, however, that a constant intake of  $\text{Sr}^{90}$  will not give a non-uniform contamination of the skeleton in the sense described above. The mechanism of remodeling and exchange gives rise to a biological half life for  $\text{Sr}^{90}$  in the skeleton, and the radioactive decay has some influence, as well, on the

<sup>1</sup>Instructions for preparing reports: Begin the report with an abstract of from 45 to 55 words. The abstract should not repeat phrases employed in the title. It should work with the title to give the reader a summary of the results presented in the report proper. (Since this requirement has only recently gone into effect, not all reports that are now being published as yet observe it.)

Type manuscripts double spaced and submit one ribbon copy and one carbon copy. Limit the report proper to the equivalent of 1,200 words. This space includes that occupied by illustrative material as well as by the references and notes.

Limit illustrative material to one 2-column figure (that is, a figure whose width equals two columns of text) or to one 2-column table or to two 1-column illustrations, which may consist of two figures or two tables or one of each.

For further details see "Suggestions to Contributors" (Science, vol. 125, p. 16 (1957)).



equilibrium state. If we assume an effective half life of 2,700 days (7.4 years), the  $\text{Sr}^{90}$  concentration may be expected to vary from the average by a factor of about 2 for a 15-year period and by successively larger factors for longer periods. To some extent this fact is accounted for by the differences in mineralization. Therefore, in the case of chronic poisoning with  $\text{Sr}^{90}$ , a higher figure than 0.1  $\mu\text{c}$  is tolerable as total body burden; tentatively, the 1  $\mu\text{c}$  level may be considered to be tolerable.

Today the  $\text{Sr}^{90}$  contamination of the geosphere and the biosphere is steadily increasing. This corresponds to a situation with aspects that lie somewhere between those of acute and chronic  $\text{Sr}^{90}$  poisoning. Children in the 0- to 5-year age group are examples of individuals with chronic poisoning conditions. Adults above 20 years of age are more likely to be examples of acute poisoning.

It should finally be pointed out that the conditions described here in relation to  $\text{Sr}^{90}$  have their counterpart for other isotopes. For instance, it seems that the evaluation of the hazards from radium poisoning should take into account the difference between acute and chronic poisoning. This is the more advisable since the short range of Ra alpha particles will cause greater differences in the local dose rates than is the case with  $\text{Sr}^{90}$ .

R. BJÖRNERSTEDT,

Research Institute of National Defense, Stockholm, Sweden.

A. ENGSTRÖM,

Department of Medical Physics, Karolinska Institutet, Stockholm, Sweden.

#### NOTES

(1) An extensive bibliography is to be found in A. Engström et al., "Bone and Radiostrontium" (Almqvist and Wikell, Stockholm, 1958).

(2) This article is pt. 3 of a series on health hazards from fission products and fallout; for pt. 1, see K. Low and R. Björnerstedt, *Arkiv Fysik*, vol. 13, p. 85 (1957); pt. 2, by R. Björnerstedt, is in preparation.

#### STATEMENT CONCERNING FALLOUT

By Charles C. Price, Blanchard professor of chemistry and chairman of the Chemistry Department, University of Pennsylvania, Philadelphia, Pa.

There are three points concerning the hazards of radioactive fallout from nuclear explosions which, it seems to me, deserve to be given more serious public attention. All three relate to the impression the public receives concerning the concept of "maximum permissible concentration" of radioactive materials.

First, let us consider the debate about the so-called threshold dose, below which it is alleged there will be no effect from added burden of radioactive contamination. It is commonly agreed that there is indeed no "harmless" dose of radiation, that any exposure will produce some chance of harmful effect. Furthermore, even if there were a "threshold" dose, it is further generally agreed that the natural background radiation to which we are all continually exposed is sufficient to be responsible for an appreciable incidence of leukemia, cancer, and mutations. The fallout from bomb testing, even though only a small fraction of natural background radiation, can thus only add to the damage already caused by natural radiation.

In view of the acknowledged damage from natural background radiation, I therefore conclude that the argument about whether there may indeed be a "threshold" for some radiation effects is largely academic, since none of us can live in the absence of damaging natural radiation levels.

A second related point is the impression created that radioactive contamination below the "maximum permissible concentration" is indeed harmless. It is in fact agreed even by AEC scientists that this is not true. If the "maximum permissible concentration" does indeed involve a hazard of some degree, particularly as applied to exposure of the general population, it becomes extremely important to state the basis on which the judgment of "permissible" is reached. Do the AEC scientists believe 100,000 additional cases of leukemia a year are permissible? Or is it only 10,000 cases per year? How many additional deformed children per year do they consider permissible? I do not mean to imply we should set the "permissible" figure at zero. We do indeed accept certain hazards with modern civilization as, for instance, the 40,000 Americans who

die in automobile accidents each year. It is not clear and obvious to the general public, nor even to scientists, which deformed children or which leukemia cases were the result of bomb testing rather than natural or other causes. It is therefore extremely important that the public be informed of and be willing to accept the degree of hazard which the AEC calls "permissible."

This brings me to the third point, which is that it seems extremely dangerous and undesirable to have the definition of what is "permissible" so completely lodged with the AEC. It has been demonstrated in many serious instances that this agency is indeed capable of suppressing important information detrimental to its interests and of distorting news so as to mislead the public. I therefore conclude that it would be extremely desirable to bring the U.S. Public Health Service into the role of establishing "permissible" radiation doses and of monitoring radiation hazards to a far greater extent than in the past.

DEPARTMENT OF COMMERCE,  
NATIONAL BUREAU OF STANDARDS,  
Washington, D.C., April 30, 1959.

Congressman CHET HOLIFIELD,  
Joint Atomic Energy Committee,  
House of Representatives, Washington, D.C.

DEAR CONGRESSMAN HOLIFIELD: As you are no doubt aware, some of the newspapers within the past week have carried some very confusing and conflicting stories with regard to the recently announced recommendations of the National Committee on Radiation Protection and Measurements relative to the MPC and MPP for internal emitters. One newspaper, in particular, reported a "split" between the International Commission on Radiological Protection and the NCRP. This statement is completely without justification and could do considerable harm to the ICRP and NCRP, as well as to the field, in general.

A large number of telephone calls have been received relative to this matter and in most instances it would appear that the situation has been explained satisfactorily.

This question could well arise during the course of the fallout hearings next week and because the problem has become so confused and in any event is difficult to understand, I thought that it would be worthwhile to prepare a more detailed explanation of the current situation and why it may appear to some individuals that there is, in fact, basic disagreement between the ICRP and NCRP.

I hope that the attached material will clarify this situation. I also hope that the material will be of some use to the Committee in examining this question further. I am really concerned over the fact that some individuals (I am not referring to your committee or its staff) appear to want to discredit the work of the two protection bodies. I think that I can say without fear of contradiction that considerations of the protection bodies are as sound as it is possible for them to be in the light of the existing information.

It is believed that, for the most part, many of the recommendations are in the conservative direction. Further I feel that it is most unfortunate if these bodies become unduly pressured by public opinion to make hasty recommendations when, in fact, the situation does not demand it.

Also there has been some misunderstanding with regard to the specific recommendations of the ICRP and NCRP relative to the body burden and MPC for strontium 90. This has been construed by many people as a recommendation that the body be allowed twice the dose of strontium formerly recommended. This is strictly not the case. The permissible body burden of strontium is based on a given dose to the bone in relation to that given by radium. This basic dose figure has not been raised or lowered since the 1953 recommendations. However, on the basis of information available in 1953 it was thought that 1 microcurie of strontium 90 would be the maximum body burden. More recent information has shown that the basic bone level would not be exceeded if the body burden were to reach 2 microcuries.

In 1953 a value for the MPC (water) for the population in the neighborhood of radiation installations was given as 80  $\mu\text{c}$  per liter for strontium 90. The corresponding figure for 1959 would be 100  $\mu\text{c}$  per liter. The value of 80  $\mu\text{c}$  has been used in connection with the milk evaluation program. In spite of the fact that the new value is slightly higher, personally I would see no reason why the

older and slightly more conservative figure should not be used. As a matter of fact, the difference between 80 and 100 is smaller than the basic uncertainties in the first place. From the point of view of absolute accuracy the value of 100 would be easier to use and would certainly be satisfactory. On the other hand, the continued use of the apparently lowered figure may serve to stir up less apprehension of an already apprehensive public.

Sincerely yours,

LAURISTON S. TAYLOR,

Chairman, National Committee on Radiation Protection and Measurements.

#### PROCESS USED IN THE DEVELOPMENT OF RADIATION PROTECTION STANDARDS

Lauriston S. Taylor, Chairman, National Committee on Radiation Protection and Measurements

A press story has reported that there are basic disagreements between the recommendations of the National Committee on Radiation Protection and Measurements and the International Commission on Radiological Protection. These reports are erroneous. The difficulty may arise in part because of the complexity of the problem and the difficulty of explaining it in terms understandable to the general public. A second difficulty may arise because the reports of the two bodies are, by the normal course of procedures, usually out of phase. A third difficulty may arise from an attempt to sensationalize something that is basically not sensational.

Until about 1958 the recommendations of both the NCRP and the ICRP dealt only with problems of occupational exposure and exposure to persons outside of radiation installations resulting from operations within the installations. In 1952 the ICRP gave its first consideration to problems of genetic dose and whole population exposure. No formal report was issued.

In 1954 the NCRP issued H259, "Permissible Dose From External Sources of Ionizing Radiations," and discussed both of these problems in general terms (sec. 3.9, 5.1.1, and 6.4).

In April 1958, the ICRP dealt with the problem in slightly more specific terms and made the following statement:

"When genetic aspects of the effects of radiation are considered, the dose received by the whole population is of importance. Scientific data derived from human as distinct from experimental animal populations are so scanty that no precise permissible dose for a population can, at present, be set. The available information is being assessed by the Commission and other groups including geneticists. Until general agreement is reached, it is prudent to limit the dose of radiation received by gametes from all sources additional to the natural background to an amount of the order of the natural background in presently inhabited regions of the earth."

At the same time it dealt with the occupational genetic dose problem (for internal emitters) as follows:

"It was proposed that the maximum permissible weekly dose for occupational exposure continue to be 0.3 rem for all organs of the body with the exception of the gonads and the total body. In cases in which the gonads are the critical body organs, the maximum permissible weekly dose was reduced to 0.1 rem in order to limit the gonad dose to not more than 50 rem before the age of 30. This reduction was made with the intention of preventing damage to man during his most reproductive period. In the cases where the total body is the critical organ the maximum permissible weekly dose was again set at 0.1 rem. This reduction will limit the accumulated dose in the total body up to the age of 60 to not more than 200 rem and is intended to reduce the probability of damage resulting from total body exposure, e.g., reduce the probability of leukemia and reduce the possibility of shortening the life span of the individual."

Both of these statements required substantial "sharpening" to be of any use in practical situations. This was done by the NCRP in its statements of January 7, 1957, and April 15, 1958. Their basic recommendations were as follows:

#### "EXTERNAL EXPOSURE TO CRITICAL ORGANS

"Whole body, head and trunk, active blood-forming organs, or gonads:

"The maximum permissible dose (MPD), to the most critical organs, accumulated at any age, shall not exceed 5 rems multiplied by the number of years

#### "INTERNAL EXPOSURES

"The maximum permissible average concentrations of radionuclides in air and water are determined from biological data whenever such data are available, or are calculated on the basis of an averaged annual dose of 15 rems for most individual organs of the body, 30 rems when the critical organ is the thyroid or skin, and 5 rems when the gonads or the whole body is the critical organ. For bone seekers the maximum permissible limit is based on the distribution of the deposit, the RBE, and a comparison of the energy release in the bone with the energy release delivered by a maximum permissible body burden of 0.1-Ra<sup>226</sup> plus daughters."

#### "MPD RECOMMENDATIONS FOR THE WHOLE POPULATION

"The maximum permissible dose to the gonads for the population of the United States as a whole from all sources of radiation, including medical and other manmade sources, and background, shall not exceed 14 million man-rems per million of population over the period from conception up to age 30, and one-third that amount in each decade thereafter. Averaging should be done for the population group in which cross-breeding may be expected."

This would break down as follows:

|                              | Man-rems  |
|------------------------------|-----------|
| Background.....              | 4,000,000 |
| Medical.....                 | 5,000,000 |
| All other <sup>1</sup> ..... | 5,000,000 |

<sup>1</sup> It is this latter component above that is considered in the 1958 ICRP report.

While stated more specifically and in different terminology, these NRCF (1957) recommendations are in full accord with those of the ICRP (1956). In March 1958, the ICRP met for the purpose of sharpening its general statements adopted in 1956. For occupational exposure they adopted the age prorated dose principle as recommended by the NCRP in January 1957. The value of body burden, and the MPC's for internal emitters were developed in cooperation with the NCRP so that the recommendations by both bodies are identical in this respect.

In addition the ICRP decided to spell out in more detail the means by which the population genetic dose principle enunciated by the ICRP in 1956 and the NCRP in 1957 might be applied in long-range planning. They added a tentative limitation for the average somatic dose to the population in accord with their own (1956) and NCRP (1954) principles stated earlier in general terms:

"No specific recommendations are made at this time as to the maximum permissible 'somatically' relevant dose to the population. However, it is expected that the maximum permissible limits of the individual total doses recommended in paragraphs 46-57 will keep the average dose in any tissue at such a level that the injuries that could possibly occur in a population would be well within acceptable limits."

The principles of the new recommendations were adopted in September 1958.

In November 1958 the NCRP set up a special ad hoc subcommittee to consider the ICRP population dose recommendations. This subcommittee has not reported out its final findings which must then be studied and approved by the whole committee before release. This takes time, and the committee feels that it is more important to be right than to be quick, particularly when the urgency is not real.

The 1958 ICRP report gave an illustration of one means for controlling the "genetic dose" (5 million man-rems per million of population up to age 30, or an average per capita dose of 5 rems) for long-range planning purposes. The example states that when large population groups are exposed to radiation where the hazard is of genetic nature, the MPD should be 1/100 of that for radiation workers; where the hazard is somatic, the MPD should be 1/30 that for radiation workers. The application of these figures depends upon the fraction of population exposed in accordance with the statement:

"Proper planning for nuclear power programs and other peaceful uses of atomic energy on a large scale requires a limitation of the exposure of whole populations, partly by limiting the individual doses and partly by limiting the number of persons exposed."

The report states further:

"Furthermore, it must be realized that the factors influencing the balancing of risks and benefits will vary from country to country and that the final decision rests with each country."

It is partly because of this last statement that the NCRP decided to examine the tentative ICRP recommendations on population dose given above. Initial conclusions of the ad hoc committee, if stated quantitatively, would lead to essentially the same MPD values for the population as recommended by the ICRP, even though the approach might be slightly different. The fact that the NCRP decided to study the tentative ICRP recommendations before adopting them should in no sense be construed as disagreeing with them. This is normal operating procedure.

On April 23 the NCRP made a press release announcing the completion of the revision of its 1953 report. This advance release, unusual for the NCRP, was made to put an end to press rumors regarding the new recommendations that were causing confusion and uncertainty as to our radiation health situation.

The basic ICRP report had been published a month earlier in England. The ICRP report on internal emitters will be published about the same time as the corresponding NCRP report (June).

However, the NCRP has not yet completed its consideration of the population dose problem and hence that portion of the ICRP report will not be released by the NCRP with its internal dose report in June. It is for this reason the April 23 press release stated: "The ICRP has made some tentative recommendations relative to whole population exposure. These are designed for long-range planning purposes and in this connection the NCRP considers them to be sound. They are not, however, subject to direct control in the immediate future. In the meantime, the NCRP considers that undue risks to the population will not be incurred by following current policies for a while longer, during which time it is hoped that methods may be established for a meaningful analysis and control of population exposure."

This statement was made because it was known that the basic ICRP report has been published; it was intended to indicate that the NCRP did not disagree with the ICRP report. The statement of the press release may have been unfortunate in that it led at least one reporter to imagine that there was a disagreement between the two bodies. However, the situation was explained in more detail to anyone who inquired about it. There is, in fact, no disagreement. Had the NCRP been allowed to proceed in its normal course of study and action without publicity, the current confusion would not have arisen. The NCRP and ICRP have always been slightly out of phase in the development of their philosophy and recommendations—this is a normal part of the orderly process of such developments.

Extracts from "Recommendations of International Commission on Radiological Protection" (adopted Sept. 9, 1958)

## B. BASIC CONCEPTS

### OBJECTIVES OF RADIATION PROTECTION

(23) Exposure to ionizing radiation can result in injuries that manifest themselves as impaired fertility, cataracts, and shortening of life. Genetic injuries manifest and genetic injuries respectively.

(24) Late somatic injuries include leukemia and other malignant diseases, impaired fertility, cataracts and shortening of life. Genetic injuries manifest themselves in the offspring of irradiated individuals, and may not be apparent for many generations. Their detrimental effect can spread throughout a population by mating of exposed individuals with other members of the population.

(25) The objectives of radiation protection are to prevent or minimize somatic injuries and to minimize the deterioration of the genetic constitution of the population.

### CRITICAL ORGANS AND TISSUES

(26) The organs and tissues of the body exhibit varying degrees of radiosensitivity, and it is therefore necessary, for purposes of protection, to consider their radiosensitivity with respect to specific functions as well as the doses they receive. When this is done, some organs and tissues assume a greater importance

according to the circumstances under which they are irradiated. They are then said to be critical.

(27) In the case of more or less uniform irradiation of the whole body, the critical tissues are those tissues of the body that are most radiosensitive with respect to the ability of carrying out functions essential to the body as a whole. In this report these are taken to be the blood-forming organs, the gonads, and the lenses of the eyes. In previous reports the skin was listed as a critical organ in the case of whole body exposure. The presentation of the recommendations in the present report is simplified by not designating the skin as a critical organ.

(28) In the case of irradiation more or less limited to portions of the body, the critical tissue is that tissue most likely to be permanently damaged either because of its inherent radiosensitivity, or because of a combination of radiosensitivity and localized high dose.

### PERMISSIBLE DOSE

(29) Any departure from the environmental conditions in which man has evolved may entail a risk of deleterious effects. It is therefore assumed that long continued exposure to ionizing radiation additional to that due to natural radiation involves some risk. However, man cannot entirely dispense with the use of ionizing radiations, and therefore the problem in practice is to limit the radiation dose to that which involves a risk that is not unacceptable to the individual and to the population at large. This is called a permissible dose.

(30) The permissible dose for an individual is that dose, accumulated over a long period of time or resulting from a single exposure, which, in the light of present knowledge, carries a negligible probability of severe somatic or genetic injuries; furthermore, it is such a dose that any effects that ensue more frequently are limited to those of a minor nature that would not be considered unacceptable by the exposed individual and by competent medical authorities.

(31) Any severe somatic injuries (e.g., leukemia) that might result from exposure of individuals to the permissible dose would be limited to an exceedingly small fraction of the exposed group; effects such as shortening of lifespan, which might be expected to occur more frequently, would be very slight and would likely be hidden by normal biological variations. The permissible doses can therefore be expected to produce effects that could be detectable only by statistical methods applied to large groups.

(32) The permissible dose to the gonads for the whole population is limited primarily by considerations with respect to genetic effects (see pars. 58-65).

### CATEGORIES OF EXPOSURE

(33) These recommendations are designed to limit not only somatic but also genetic effects; it is therefore necessary to reduce as much as possible the dose to the population as a whole, as well as to the individual. In general, doses resulting from all sources of ionizing radiation should be considered in the appraisal of possible biological damage. However, practical considerations make it necessary to consider separately the doses resulting from two categories of exposure, namely:

(a) Exposure to natural background radiation.

(b) Exposure resulting from medical procedures.

(34) Natural background radiation varies considerably from locality to locality and the doses it contributes to the various organs are not well known. If maximum permissible limits recommended by the Commission included background radiation, the allowable contribution from manmade sources—which are the only ones that can be controlled—would be uncertain and would have to be different for different localities. Accordingly, doses resulting from natural background radiation are excluded from all maximum permissible doses recommended in this report.

(35) In medical procedures, exposure of the patient to primary radiation is generally limited to parts of the body, but the whole body is exposed to some extent to stray radiation. The contributions to the doses in various organs and the part played in the overall effects on the individual are practically impossible to evaluate at the present time. The Commission recognizes especially the importance of the gonad doses resulting from medical exposure and the attendant genetic hazard to the population. Accordingly, it recommends that the medical profession exercise great care in the use of ionizing radiation in



ductive periods be kept at the minimum value consistent with medical requirements. However, individual doses resulting from medical exposure are excluded from all maximum permissible doses recommended in this report.

(36) The recommendations cover the following categories of exposure. In principle both the exposure of individuals and averages over the whole population have to be considered, but recommendations with regard to individual exposure are given only for the groups A and B.

A. Occupational exposure.

B. Exposure of special groups:

(a) Adults who work in the vicinity of controlled areas (see para. 71 and 72), but who are not themselves employed on work causing exposure to radiation.

(b) Adults who enter controlled areas occasionally in the course of their duties, but are not regarded as radiation workers.

(c) Members of the public living in the neighborhood of controlled areas.

C. Exposure of the population at large.

D. Medical exposure.

*Occupational exposure*

(37) Exposure of an individual who normally works in a controlled area constitutes occupational exposure. Maximum permissible doses are set for the individuals in the small portion of the population that can be occupationally exposed (para. 46-52). The contribution from this group to the genetic dose to the population as a whole is discussed in paragraph 65.

*Exposure of special groups*

(38) Persons who only occasionally enter a controlled area and persons who work or reside in the vicinity of an controlled area may be exposed to radiation originating in the controlled area. They constitute groups that may include children and pregnant women as well as individuals subject to other hazards, and may in total constitute a large fraction of the whole population. For these reasons the maximum permissible dose to these persons as individuals is set lower than for persons occupationally exposed (para. 53-57). The contribution from these groups to the genetic dose to the whole population is discussed in paragraph 65.

*Exposure of the population at large*

(39) Members of the population at large may be exposed to radiation that cannot be related to any specific controlled area; e.g., exposure from environmental contamination and widely distributed radiation sources such as wrist watches, TV sets, and various applications of radioactive materials to be expected as a result of future expansion in the atomic energy field. As such exposure is not easily controlled, it will be impossible to insure that a recommended maximum permissible individual dose is not exceeded in any single case. Where large numbers are involved, it will not be possible to examine the habits of every individual. A reasonable procedure would be to study a sample of the group involved and to set the environmental level so that no individual in the sample receives any excessive exposure. There will always remain the possibility that someone of grossly different habits from those in the observed sample may receive a higher dose than the maximum in the sample.

(40) In order to facilitate planning for the anticipated increased uses of nuclear energy and other sources of radiation, it is desirable at this time to recommend a maximum for the genetic dose to the population (par. 64); this maximum will determine what average gonad exposure could be allowed. Part of the recommended maximum genetic dose will have to be used for exposure of groups such as A and B and for medical exposure. The proper apportionment for exposure of the population at large must allow for both internal and external exposure (par. 65).

*Medical exposure*

(41) No recommendations are given with regard to the dose to the individual from medical exposure. (The contribution of medical exposure to the genetic dose is discussed in para. 69-70.)

REDUCTION IN MAXIMUM PERMISSIBLE DOSE

(42) The new recommendations were introduced partly with the intention of

lation, and partly to limit the probability of somatic injury by reducing the lifetime dose. This reduction does not result from positive evidence of damage due to the use of the earlier permissible dose levels, but rather is based on the concept that biological recovery may be minimal at such low dose levels.

TIME INTERVAL OVER WHICH DOSE IS TO BE ASSESSED

(43) The maximum permissible weekly doses recommended by the Commission in 1950 have been replaced by limits for the doses received over longer periods of time (para. 47-49). In the case of occupational exposure the maximum permissible dose that may be accumulated at a certain time depends on the age of the worker. The dose to individuals in the population at large, or in special groups other than occupational, may be accumulated at a rate that is determined by a maximum permissible annual dose. The genetic dose to the whole population is assessed over the period between conception of the individual and conception of each child of the individual. (See par. 63 for method of evaluation.)

(44) These extended periods of time allow for some flexibility in the way in which radiation exposure may be received, and at the same time provide what is considered to be adequate protection for each group of the population.

C. MAXIMUM PERMISSIBLE DOSES

GENERAL

(45) It is emphasized that the maximum permissible doses recommended in this section are maximum values; the Commission recommends that all doses be kept as low as practicable, and that any unnecessary exposure be avoided.

EXPOSURE OF INDIVIDUALS

OCCUPATIONAL EXPOSURE

(46) In any organ or tissue the total dose due to occupational exposure shall comprise the dose contributed by external sources during working hours and the dose contributed by internal sources taken into the body during working hours. It shall not include any medical exposure or exposure to natural radiation.

*Exposure of the gonads, the blood-forming organs and the lenses of the eyes*

(47) The maximum permissible total dose accumulated in the gonada, the blood-forming organs and lenses of the eyes at any age over 18 years shall be governed by the relation  $D=5(N-18)$  where  $D$  is tissue dose in rems and  $N$  is age in years.

(48) For a person who is occupationally exposed at a constant rate from age 18 years, the formula implies a maximum weekly dose of 0.1 rem. It is recommended that this value be used for purposes of planning and design.

*Rate of dose accumulation*

(49) To the extent the formula permits, an occupationally exposed person may accumulate the maximum permissible dose at a rate not in excess of 3 rems during any period of 13 consecutive weeks (i.e., in no 13 consecutive weeks shall the dose exceed 3 rems). If necessary, the 3 rems may be received as a single dose, but as the scientific knowledge of the biological effects of differing dose rates is scant, single doses of the order of 3 rems should be avoided as far as practicable.

*Application to special cases*

(50) Setting permissible limits of exposure in terms of the dose accumulated up to a given age introduces certain practical complications. Thus, some workers (previously exposed at levels within the then permissible limits) may have already accumulated a dose in excess of the maximum permitted by the formula. There are also special cases in which exceptions in the application of the formula may be desirable for practical reasons and are justifiable within the context of paragraph 42. The following recommendations are intended to provide guidance on administrative policy, which may well vary according to circumstances at the local level. (It should be noted that this situation will obtain only during a relatively short transition period.)



sons receive doses which are considerably less than the maximum permissible doses.

(d) *Exposure of special group.*—Since the contribution from the special groups is largely due to group B(c) an apportionment of 0.5 rem for the special groups would imply that about 3 percent could be exposed to the maximum permissible individual annual gonad doses for these groups. The allowable size of these groups varies inversely with the average dose within the groups. Thus, if this dose were only 10 percent of the maximum individual doses, the groups could amount to 30 percent of the whole population, which is very much larger than is likely to occur.

(c) *Exposure of the population at large.*—The apportionment of 2.0 rems (with a long-term reserve of 1.5 rems for possible eventualities) for the genetic exposure of the population at large is intended for planning purposes in the development of nuclear energy programs (with the associated waste disposal problems) and more extensive uses of radiation sources. In the case of internal exposure, the radioisotopes of interest are those that contribute to the gonad dose directly (by local concentration) or indirectly (by radiation produced elsewhere in the body). In either case the maximum permissible concentrations in air and water of these isotopes recommended by committee II for continuous occupational exposure ("168-hour week") are based on an average yearly dose of 5 rems in the gonads or the whole body. If for these isotopes the average concentrations in public air and water supplies are lower than the values recommended for continuous occupational exposure by a factor of 1/100, the genetic dose to the population would amount to 1.5 rems ( $5 \times 1/100$  rems/year in the gonads  $\times 30$  years = 1.5 rems). In this case the contribution from external sources should be limited to 0.5 rem in order not to exceed the total of 2 rems.

#### SOMATIC DOSE

(66) No specific recommendations are made at this time as to the maximum permissible "somatically" relevant dose to the population. However, it is expected that the maximum permissible limits of the individual total doses recommended in paragraphs 46-57 will keep the average dose in any tissue at such a level that the injuries that could possibly occur in a population would be well within acceptable limits. (See par. 31.)

(67) In the case of external exposure of the whole body to penetrating radiation the restriction imposed by the genetic dose to the population automatically reduces the doses to internal organs below the individual maximum permissible annual doses recommended in paragraphs 46-57. Thus the probability of somatic injury in these organs is considerably lower than indicated in paragraph 66. The same thing applies to internal exposure resulting from radioisotopes that directly or indirectly contribute to gonad dose of a population. (See addendum to par. 65.)

(68) There remain for further consideration those isotopes that concentrate in specific organs (other than the gonads). In view of the existing uncertainty as to the dose-effect relationships for somatic effects, it is suggested that for planning purposes the average concentrations of such isotopes, or mixtures thereof, in air or water, applicable to the population at large, should not exceed one-thirtieth of the MPC values for continuous occupational exposure given in the report of committee II.

## APPENDIX F

### BIOLOGICAL EFFECTS

DEPARTMENT OF RADIOTHERAPEUTICS,  
UNIVERSITY OF CAMBRIDGE,  
Cambridge, England, April 27, 1959.

HON. CHET HOLIFIELD,  
The House of Representatives,  
Washington, D.C.

DEAR MR. HOLIFIELD: Enclosed are the two summaries of the two reports for the forthcoming congressional hearings on the problem of "fallout". The delay in sending these reports is the result of informing various people involved with these investigations of the submission of these reports for the hearings, as well as securing permission from the publishing houses in whose journals they will eventually appear. As yet I have not completed these matters, however I am sending them on to you because of the shortness of time before the hearings. In the event there are any objections to having either of the reports incorporated I will let you know.

I believe that both of these reports will be of interest to individuals interested in the fallout problem. The use of the ion-exchange column and artificial kidney offer two new attempts at removal of internally deposited radioactive materials. We were able to remove 30 to 40 percent of the injected dose of strontium shortly after injection in dogs, but the amount removed fell rapidly with time. The procedure may be of use in the removal of radioactive materials from the blood stream, thus preventing damage to the kidneys. The results also showed that the primary part removed the first few hours would have eventually been eliminated the first week. However, full investigation of the potentialities of the method have not been carried out at present. It may be that this method used in conjunction with other methods may be more effective than either used independently.

It may also be of interest that this method has many potential uses for studying the dynamics of the metabolism of radioisotopes of stable elements in the body. The medical division of the International Atomic Energy Agency is exploring the possible use of this inexpensive apparatus for adaptation in the introduction of medical and biological uses of radioisotopes in underdeveloped countries.

The investigation of the late clinical findings following thorotrast administration is important for numerous reasons. These patients constitute one of the largest sources of humans in the United States for the study of the long-term effects of continuous low level irradiation in man. You will note that rare tumors of the liver, the organ of greatest thorium disposition, are beginning to occur in these patients. The activity in the bone marrow is sufficiently great to make these patients an excellent source of material for the study of radiation induced leukemia.

The study made in Washington is, in essence, a pilot study, and it is hoped that a national followup study of the people can be initiated. Some preliminary discussions have been held in Washington under the auspices of the subcommittee of radiology of the National Research Council with representatives of the U.S. Public Health Service, Veterans' Administration, and the Medical Department of the Navy and the Atomic Energy Commission. We are meeting in London, prior to the International Radiological Congress in Germany this summer, in an attempt to formulate possible means for going about a national followup study.

Please do not hesitate to let me know if there are any questions about these reports. I appreciated the opportunity of discussing these matters of mutual interest with you while in Washington. Again, I want you to know that I think that you are performing a very useful and important public service.

Very sincerely,

WILLIAM B. LOONEY, M.D.

A STUDY OF THE DYNAMICS OF STRONTIUM AND CALCIUM

METABOLISM AND RADIOELEMENT REMOVAL

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### INTRODUCTION

The classic studies of Aub, Evans, Gallagher and Tibbets (1) in 1938 in radioelement removal demonstrated that the renal clearance for radium was less than 1 percent in twenty-four hours. This finding suggested the possibility that direct removal from the blood might prove to be an effective way of eliminating radioactive materials. Both the artificial kidney (2) and ion-exchange resins (3) afford means for radioelement removal as well as providing an opportunity for extension of the work by Hastings and Huggins (4) on the mobilization of calcium in the circulating body fluids (5,6,7). The utilization of two radioisotopes of strontium and one radioisotope of calcium has also permitted an extension of previous studies of the metabolism of both strontium and calcium. (8-17)

The circulation of blood through an ion-exchange resin offers a wide range of potential application to biological and clinical investigation. Appropriate adjustment of the cation concentrations in the column permits preferential removal of particular cations of interest. The ability to place electrolytes of a biological system out of equilibrium affords an excellent tool for the study of the dynamics of both administered radioisotopes and stable electrolytes of the biological system.

### MATERIAL AND METHODS

This study of the dynamics of strontium and calcium metabolism has been made by circulation of the blood of 18 dogs either through an artificial kidney or an ion-exchange column for periods ranging from 1.5 to 7 hours (see Fig. 1). The ion-exchange column has been primarily used because of its simplicity, economy of operation, and potential adaptation for more extensive utilization. A sulfonic acid resin was used in the cation-exchange

column, and sodium was the cation attached to the exchangeable group. Removal rates for the radioisotopes and electrolytes have been derived from the amount of the element in question removed divided by the time of blood flow through the column.

The serum Ca, Na, K, Cl,  $\text{CO}_2$ , Mg and pH were determined before, during and after the removal periods by standard methods. (18-23) With the exception of serum calcium, no marked variation in the serum concentration of the electrolytes was found. Sr-89 and Ca-45 determinations were made by the method described by Maletskos. (14) The Sr-85 determinations were made in a well-type scintillation counter.

### RESULTS

Both the artificial kidney and ion-exchange column were found to be effective methods for removal of calcium from the plasma. Changes in serum calcium concentration during and after circulation of the blood of a dog through an ion-exchange column is illustrated in Figure 2. There was a rapid fall in the serum calcium which was then sustained at a concentration of 3 milligrams percent for 2½ hours. It was necessary to stop for a half hour because of increased respiration and tetanic contractions of the dog, and the serum calcium concentrations rose rapidly. Removal was continued for 4 more hours with a depression of the serum calcium concentration to 2 milligrams percent at the termination of the experiment. During the three hour recovery period the serum calcium rose to the control value.

The rate of removal of calcium during the first 30 minutes was usually between 2.5 and 6 milligrams per minute. After this, the rate of removal was in the order of 0.5-2 milligrams per minute in most dogs.

The mean amount of radiostrontium and radiocalcium removed in 7 dogs, 1 hour after administration, was  $33.9 \pm 6.5$  percent of

which could be removed by the ion-exchange column rapidly decreased with time after administration. The mean removal of radiostrontium and radiocalcium in 9 dogs from 12 hours to 3 days after administration was only  $6.5 \pm 3.1$  percent of the injected dose.

These data define more precisely than the rates of stable calcium removal the fact that calcium is being removed from at least two hypothetical body compartments. Twelve percent of the dose was removed from the first compartment, with a half time of 20 minutes. The remainder of the injected dose removed came from a hypothetical compartment with a half time of removal of 11 hours.

The following experiment illustrates the use of the three isotopes for the study of the removal of strontium and calcium by the ion-exchange column. Ca-45 and Sr-85 were injected 69 minutes before removal, and Sr-89 three days before removal in a dog (CK-127) (see Fig. 3). A total of 29.6 percent of the injected Ca-45 and 31.3 percent of the injected Sr-85 was removed after circulation of the blood through the ion-exchange column for 5 hours. Only 1.9 percent of the Sr-89 injected 3 days before was removed. Approximately 1 percent of the injected amount of the three radioisotopes was removed in the second experiment conducted one week after the first experiment.

Infusion of calcium gluconate into the blood leaving the ion-exchange column was made at a rate to maintain the serum calcium concentration in the removal of radiostrontium in 2 dogs. The radiostrontium removal with calcium infusion was similar to its removal without calcium administration.

One of the major questions concerning the removal of radio-calcium and radiostrontium by the ion-exchange column was the question of alteration of the normal elimination of the radio-isotope in the excreta. The practical value of radioelement removal in man will depend to a large extent upon the removal of a significant fraction of the radioelement by the artificial

eliminated in the excreta. Results from excretion studies in 4 dogs over a 7 to 10 day period have shown that radioisotopes removed by the ion-exchange column would have been eliminated eventually in the excreta. This is illustrated by the results of the study on Dog CK-127 (see Fig. 4). During the three day period before connecting the dog to the ion-exchange column about 45 percent of the injected dose of the Sr-89 had been excreted, and only 1.9 percent was removed by the ion-exchange column. Thirty percent of the Sr-85 injected 69 minutes before the dog was connected to the ion-exchange column was removed. However, the total amount of both Sr-85 and Sr-89 remaining in the dog at the end of the experiment was approximately the same.

Results of the renal clearance before, during and after connecting the dog to the ion-exchange column were made in 5 dogs. The compared changes in the renal clearance of Na, K, P, Ca-40, Ca-45, Sr-85 and Sr-89 have given results which warrant further study. There was, in general, a reduction in renal clearance of both stable and radioactive cations during the period of removal.

#### DISCUSSION

The ability of the ion-exchange column and the artificial kidney to remove calcium from the plasma at a rate equal to, or faster than, its rate of mobilisation from bone gives a means for extending the study of calcium metabolism which has not been heretofore feasible.

The removal rate of calcium-40 from the plasma the first 30 minutes was between 2.5 and 6 milligrams per minute. This was considered to be the combined removal from both extracellular fluid and bone. The removal rate after 30 minutes was between 0.5 and 2 milligrams per minute. It is therefore considered that the removal rate of calcium of 2 milligrams per minute is a reasonable estimate for the maximum rate of mobilization of

calcium from bone after depletion of the calcium in the extracellular fluid. Analysis of the removal rate of radiocalcium more precisely defines the removal of stable calcium from the extracellular fluid and bone. (See Table I). Two distinct rates of removal were found for radiocalcium. The mean removal of 12 percent of the injected dose of strontium and calcium was from a hypothetical compartment with a half time of removal of 20 minutes. Since the estimates of the injected radioisotopes in the plasma at comparable times was 11.6 percent, it is considered that the major part of the radioisotope removed with a half time of removal of 20 minutes came from the plasma. The remainder of the radioisotopes removed is considered to represent a composite curve of removal from the interstitial fluid and bone.

The decreased efficiency of removal of radiostrontium and radiocalcium by the ion-exchange column after 12 hours to 6 to 12 percent of the dose would suggest that a major change in incorporation of the two radioisotopes in bone occurs between one hour and 12 hours.

The results of the renal clearance studies in 5 dogs are considered to be preliminary. There was a reduction in the renal clearance of radiostrontium compared to radiocalcium and stable calcium after connecting the dog to the ion-exchange column. If there is competitive reabsorption of strontium and calcium by the kidney tubules, then the reduced excretion of calcium as a result of depressed serum calcium may cause a relative increase in tubular reabsorption of radiostrontium.

#### SUMMARY AND CONCLUSIONS

An estimate of the maximum rate of calcium mobilization has been obtained by circulating the blood of dogs either through an ion-exchange column or artificial kidney. The utilization of

two radioisotopes of strontium and one radioisotope of calcium gave a means for comparing strontium and calcium metabolism under non-equilibrium conditions. The methods described are also of theoretical value in decreasing exposure of the kidney to nephrotoxic elements.

#### ACKNOWLEDGEMENTS

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The magnesium determinations were obtained through the courtesy of Dr. Benjamin Barnes and Mrs. Leo Gordon of the Surgical Laboratory of the Mass. General Hospital.

TABLE I

Removal of Radiocalcium and Radiostrontium From Two Hypothetical  
Compartments Approximately One Hour After Injection  
(Seven Dogs)

| Dog    | Isotope          | Percent dose removed from compartment 1 | Percent dose removed from compartments 1 and 2 | Percent dose removed from compartments 1 and 2 minus percent dose removed from compartment 1 | Half time of removal from compartment 1 (minutes) | Half time of removal from compartment 2 (hours) |
|--------|------------------|-----------------------------------------|------------------------------------------------|----------------------------------------------------------------------------------------------|---------------------------------------------------|-------------------------------------------------|
| CK 121 | Ca <sup>45</sup> | 12                                      | 40.7                                           | 28.7                                                                                         | 18                                                | 8                                               |
| CK 124 | Ca <sup>45</sup> | 6                                       | 32.2                                           | 26.2                                                                                         | 15                                                | 17.5                                            |
| CK 130 | Sr <sup>85</sup> | 14                                      | 32.2                                           | 18.2                                                                                         | 20                                                | 13                                              |
| CK 131 | Sr <sup>85</sup> | 20                                      | 31.1                                           | 11.1                                                                                         | 20                                                | 7                                               |
| CK 132 | Ca <sup>45</sup> | 9.5                                     | 22.5                                           | 13.1                                                                                         | 35                                                | 20                                              |
| CK 134 | Sr <sup>85</sup> | 13                                      | 40.0                                           | 27.0                                                                                         | 15                                                | 7                                               |
| CK 135 | Sr <sup>85</sup> | 10                                      | 39.0                                           | 29.0                                                                                         | 20                                                | 7                                               |
| Mean   |                  | 12 ± 4.8*                               | 33.9 ± 6.5                                     | 21.9 ± 7.6                                                                                   | 20 ± .8                                           | 11 ± 5.6                                        |

\* Standard Deviation of the Mean

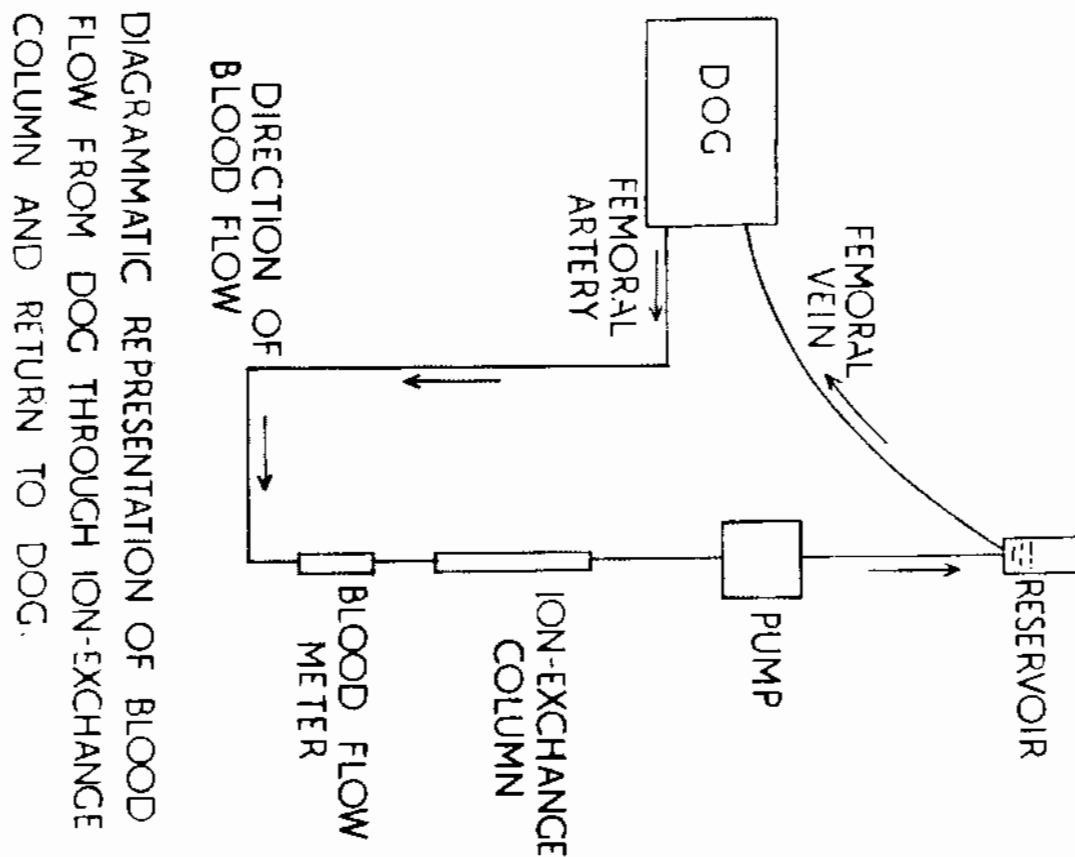


Fig. 1. Diagram of Ion-exchange Column.



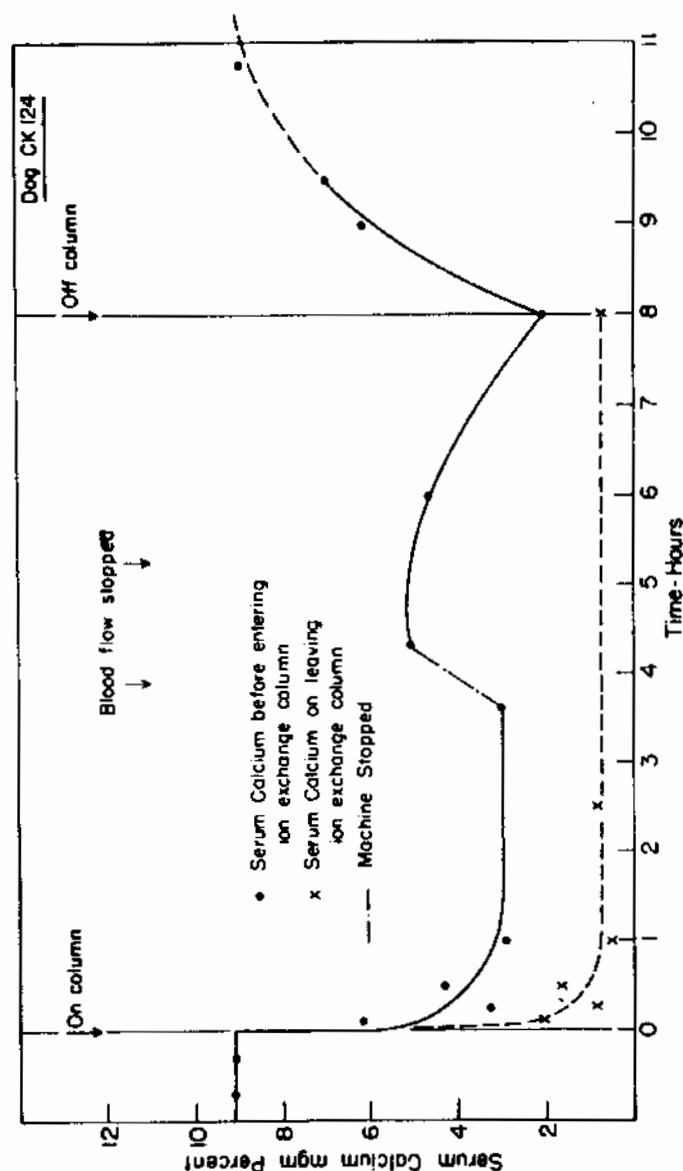


Fig. 2. Changes in the serum calcium concentration during a period of removal and recovery. Note the rise in the serum calcium level after stopping the blood flow during the period of removal. (Dog CK-124).

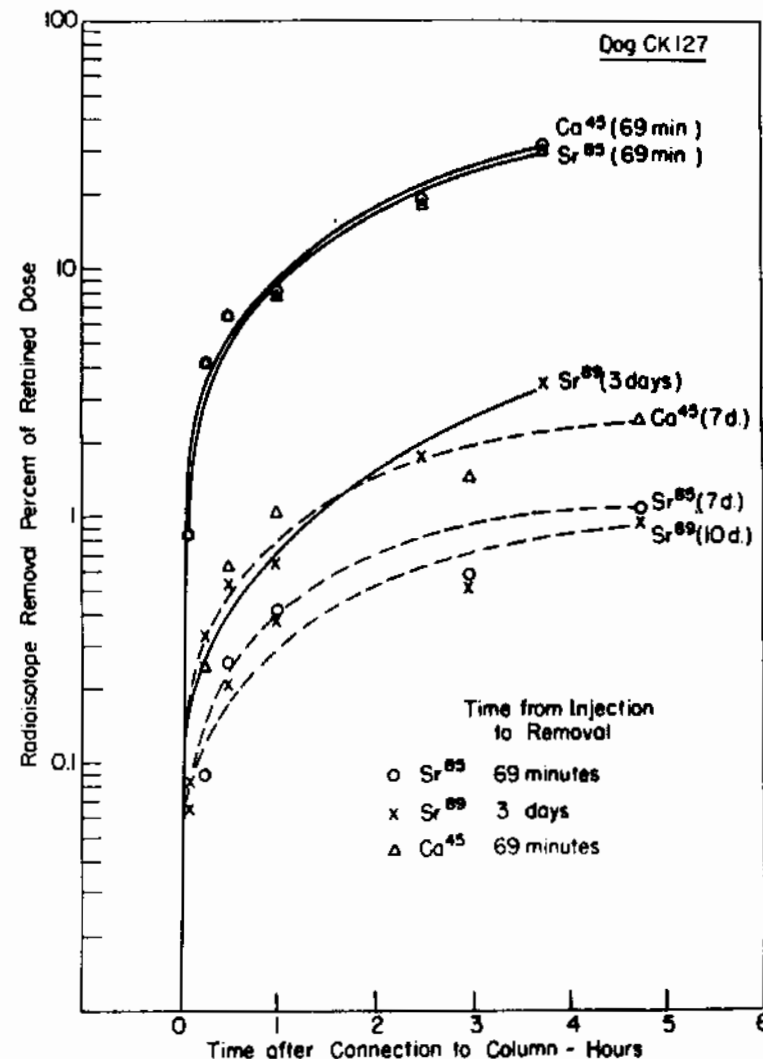


Fig. 3. Removal of Ca<sup>45</sup>, Sr<sup>89</sup> and Sr<sup>85</sup> by connecting the dog to the ion-exchange column and circulating the blood for 4 hours and 35 minutes. Sr<sup>89</sup> was injected 3 days prior as Ca<sup>45</sup> and Sr<sup>85</sup> 69 minutes prior to connecting the dog to the column. The broken curves represent the results of the 2nd removal period one week later. Values for the 2nd removal period have been corrected for excretion and they are expressed as per cent of the retained dose at

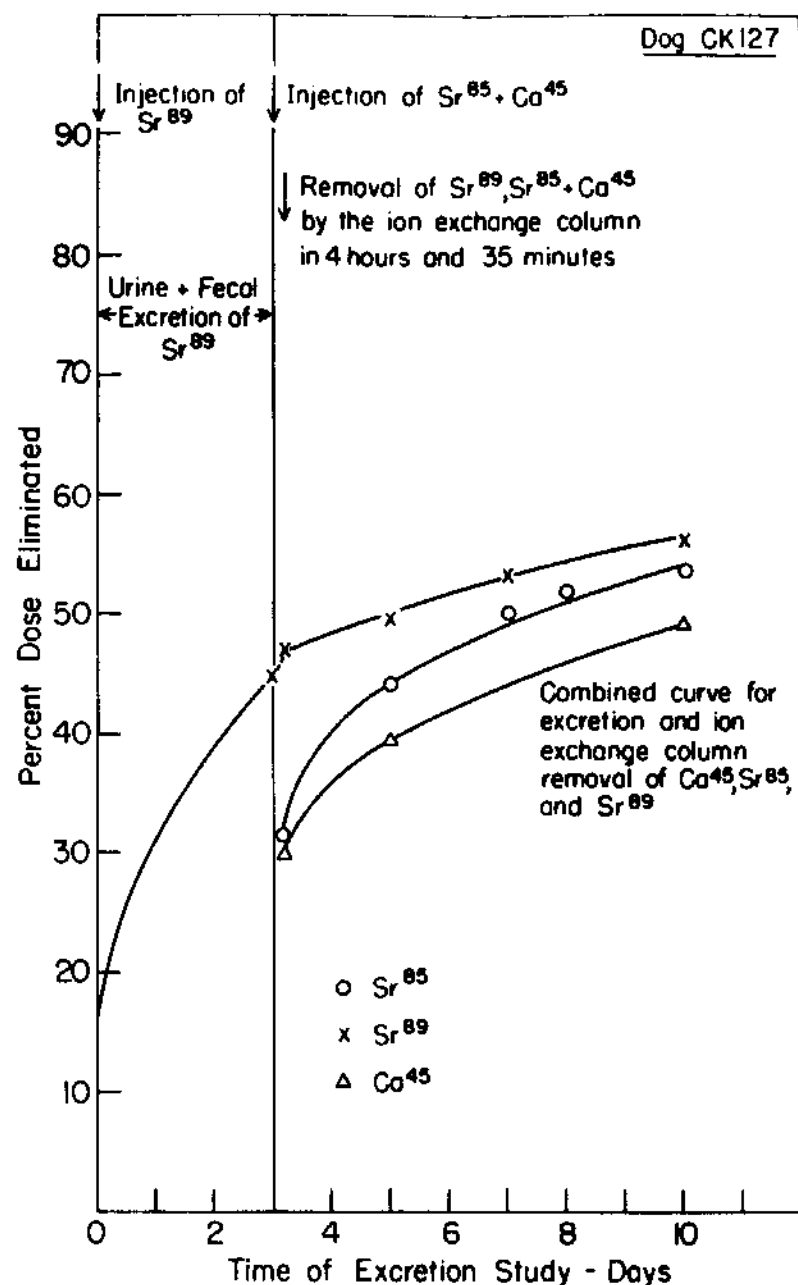


**Fig. 4.** The sum of the removal of  $\text{Ca}^{45}$ ,  $\text{Sr}^{85}$  and  $\text{Sr}^{89}$  by the ion-exchange column and the cumulative excretion of these radioisotopes 3 days before and 7 days after

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# An Investigation of the Late Clinical Findings

## Following Thorotrast (Thorium Dioxide) Administration

by

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Preliminary Results of this study were presented in part at the Fifty-Fifth Annual Meeting, American Roentgen Ray Society, Washington, D.C., September 21-24, 1954 and the Radiation Research Society Meeting, New York City, May 16-18, 1955.

The section on carcinogenesis was presented at the Seventh International Cancer Congress, London, July 6-12, 1958.

The opinions and assertions contained herein are the private ones of the author, and are not to be construed as official or reflecting the views of the Navy Department or the Naval Service at large.

Thorotrast (thorium dioxide in suspension) was first used clinically in 1928. During the period 1930-1945 it was widely used in diagnostic radiology, primarily for the visualization of the liver, spleen and cerebral arteries.<sup>13,90,93,117,128</sup> Thorotrast utilization has been curtailed in part because of sequelae which have developed from induration at sites of injection, and in part because of the recognition that thorium, the parent of a series of radioactive daughter elements, might produce clinical damage or neoplasia. A study of thorotrast patients has been made because they comprise an important source of clinical material for the study of the late effects of continuous low level radiation. In addition, the study was planned to obtain information about the various radiobiological aspects of thorium in view of its potential use as a breeder material in nuclear reactors; to obtain information about radium isotopes of the thorium decay series in view of their presence in the skeletons of luminous dial workers; and to obtain biological information about the actinide rare earths, in order that a better understanding of the late effects of members of the group (e.g. plutonium) might be obtained. It was also considered that the thorium patients would constitute a source of clinical data for utilization in the evaluation of maximum permissible levels of body burden for radioelements in use today.

A summary of previously published histopathological, autoradiographic, radiochemical and spectrochemical findings of this study is given in Part I.\* The results of the laboratory

\* A brief summary of the clinical and radiochemical aspects have been published (Looney, 1954)<sup>64</sup> (Looney and Colodzin, 1955)<sup>67</sup> (Looney, Hursh, Colodzin and Stedman, 1958)<sup>66</sup>. A joint study of the distribution of thorium and the excretion of thorium and the radium isotopes of the thorium decay series was carried out as a joint project with the Department of Radiation Biology, University of Rochester (Hursh, Stedman, Looney and Colodzin, 1957).<sup>54</sup>

The autoradiographic study was made as a joint project with the Radiobiology Laboratory, University of Utah and the Laboratory of Biological Isotopic Research, University of Copenhagen (Looney, Arnold, Levi and Jee, 1955).<sup>65</sup> Certain aspects of this study are

and clinical findings of the thorotrast patients are given in Part II. The general problem of radiation dosimetry, hematological findings, skeletal findings, clinical follow-up studies, and carcinogenesis in thorotrast patients is included in the discussion.

## P A R T I

### SUMMARY OF EXCRETION, DISTRIBUTION, AUTORADIOGRAPHIC AND HISTOPATHOLOGICAL FINDINGS

#### A. Excretion Studies

Patient M. H. was given thorotrast in an attempt to determine the etiology of jaundice. After receiving 72 cc of thorotrast she excreted approximately 0.7 percent of the thorium during the 17 days between administration of thorotrast and death from carcinoma of the pancreas. The average thorium excretion rate from the 10th to 17th day was about 0.0007 percent of the dose per day. Patient A.T. was a 34 year old male who had osteogenic sarcoma. It was estimated that between 0.04 and 0.1 percent of the thorium was eliminated in 108 days after receiving 60 cc of thorotrast. The average excretion between the 24th and 108th day was estimated to be from 0.00025 to 0.00045 percent of the dose per day. The biological half-time of thorotrast from these studies was estimated to be over 400 years.<sup>54</sup>

#### B. Distribution Studies

The thorium content of the organs of the body was determined by spectro-chemical analysis. Almost all of the thorium was present in the liver, spleen and bone marrow of the patients 17 and 49 days after administration. Small amounts were found in the lungs and adrenals. Minute amounts of thorium were present in all organs and tissues upon which the thorium content determinations were made. Distribution studies were also made

on two patients, L.W. and A.D. who had been given thorotrast 10 and 19 years prior to death (see Table 1).

The concentration of radium isotopes in the organs of highest thorium deposition and the radium isotope content of various parts of the skeleton were determined on patient M.H. 17 days after thorotrast administration and patient A.D. 19 years after administration (see Table 2).

#### C. Histological and Autoradiographic Studies

Comparisons of the histological sections of the patients who died 17 and 49 days after thorotrast administration were made with sections from patients who died 10, 18 and 19 years after administration. In the patients given thorotrast shortly before death, most of the thorotrast was present in the cells of the reticulo-endothelial system, and was rather uniformly distributed throughout the organs; whereas, in the patients examined 10, 18 and 19 years after thorotrast administration most of the thorotrast was present in aggregates. In the review of the histological specimens from the organs of patients years after administration there was in general comparatively little destruction and connective tissue replacement around the thorotrast aggregates in most of the organs studied. The major exception to this was the spleen in which a progressive destructive effect seemed to occur. With destruction of the splenic architecture and replacement fibrosis the spleen became smaller in size. Since the thorium content remains almost constant, there was an increase in the relative concentration of thorium. The spleens of some of the patients were markedly reduced to about one fifth their normal size, while in others they were almost completely destroyed.

## P A R T II

### CLINICAL STUDIES

#### A. Age and Time of Retention of Thorotrast

The status of 35 people has been determined in the National Naval Medical Center study. These people were given intravenous injections of from 3 to 15 grams of thorium dioxide as thorotrast during diagnostic radiological procedures. There were 15 patients whose diagnostic procedures usually required from 15 to 25 cc of thorotrast (3 to 5 grams of thorium) and 20 patients who had procedures usually requiring from 60 to 75 cc of thorotrast (12 to 15 grams of thorium). The mean age of the first group of patients in 1954 was 44 years, the mean time of retention was 15.6 years. The mean age of the second group in 1954 was 58 years, and the mean time of retention was 14.5 years. One patient of Group I and 13 patients of Group II are dead. The mean age at death was 62 years (see Table 3).

#### B. Roentgenographic Findings

There was increased density found in the liver and spleen of almost all of the patients examined. Roentgenograms of the liver and spleen taken shortly after administration showed that the X-ray shadow from thorotrast was smooth and confluent in appearance, while roentgenograms taken years following administration had a lacey trabeculated appearance. There was also roentgenographic evidence that some thorotrast had apparently migrated to the regional lymph nodes.

Increased densities in the neck were found in some patients in which thorotrast had been extravasated into the soft tissues. In a few instances the thorotrast had migrated in the mediastinum to the level of the heart. Chest X-rays were negative.

Skeletal roentgenographic examinations were made on 19 of the 35 patients. The examinations were repeated in five cases.

In 11 of these patients minor irregularities were observed in the tibiae, femorae, humeri, radii or ulnae. There were longitudinal striations in the shafts of some of the long bones. Increased thickness of the shafts of the tibiae and femorae were occasionally found in the middle one third.<sup>64,65,66</sup> Some bones had increased densities which appeared to be from deposits of thorotrast along the endosteum (see Tables 4 and 5).

Dental roentgenographic examinations were made on eight patients by Commander Colby of the Naval Dental School National Naval Medical Center. There was no evidence of dental changes attributable to thorotrast administration.

#### C. Hepatic Function Studies

Hepatic function studies were made on 14 of the 15 patients of Group I (see Table 4, first part of Table 6). All patients had negative histories of hepatic disease; in only one patient was the bromsulphalein test consistently abnormal.

There was a history of hepatic disease prior to thorotrast administration in 11 of the 20 patients in Group II. Only four patients had negative histories for previous liver disease. The reason for administration is unknown in the remaining five. Two of these patients are still living and enlarged livers were found at the time of thorotrast administration. It is presumed that hepatic disease was present. Thorotrast was found at autopsy in the other three.

Hepatic function studies were made on 12 of the 20 patients in Group II (see Table 5 and second part of Table 6). Abnormal hepatic function was indicated by at least one of the tests in 7 patients. Five of these patients had known histories of hepatic disease, and the two remaining patients with enlarged livers were presumed to have hepatic disease. On subsequent examination only three of the seven patients had abnormal hepatic function.

#### D. Hematological Studies

Hematological studies were made one or more times on 30 of the 35 patients. Occasionally patients had haemoglobin and erythrocyte values which were at the lower limits of normal or were slightly depressed (see Table 7).

Patient L.W. had a diagnosis of anemia made in 1937 at the time of thorotrast administration. An anemia persisted until her death in 1951. Terminally, bizarre lymphocytic and monocytic changes were found. The diagnosis of monocytic leukemia was considered by the attending physician. However, there were insufficient findings to establish a diagnosis of leukemia.

#### E. Clinical Examination

Clinical examinations of these patients were in general negative. There was little evidence of clinical damage from thorotrast. The only evident clinical effect found was induration and contraction at the sites of thorotrast extravasation into the arms and necks of some of these patients. Involvement of the vocal cords, esophagus and carotid artery were some of the indirect results occurring from induration and contraction. A summary of the pertinent clinical findings and laboratory studies is given in Tables 4 and 5.

Two patients have died from tumors of the liver since the completion of this study. The first patient M.R. died in 1955, age 52, 23 years after receiving 72 cc of thorotrast, which was given in an attempt to determine the cause of jaundice and an enlarged liver. Pathological studies were made by Swarm<sup>115</sup> and Stewart<sup>113</sup> at the National Cancer Institute. The tumor was classified as an hemangioendothelioma. Neoplastic tissue was found in the liver, spleen and bone marrow.

The second patient of this study died recently in 1958, at the age of 43, from hepatic failure and bronchopneumonia. She had received an unknown amount of thorotrast 17 years prior

to death. The pathological studies have not been completed, however the preliminary pathological report has been obtained through the courtesy of the attending physician, Dr. J.E. Fitzgerald. A multinodular primary hepatic neoplasm was found on the gross anatomic examination.

#### DISCUSSION

##### A. Radiation Dosimetry

Thorotrast is a colloidal solution containing 20 percent thorium dioxide and 20 percent dextran with 0.15 percent methyl-p-hydrobenzoate added as a preservative.<sup>90</sup> The amount of thorium dioxide used in thorotrast for a hepatogram (approximately 15 grams) has an estimated alpha-particle equivalent to 2.1 micrograms of radium on an alpha-particle energy basis, assuming that both radium and thorium are in equilibrium with their daughter products. For purposes of calculation of radiation dose, it is assumed that the thorotrast remains in the body indefinitely. Excretion studies have shown that the biological half-time for thorium is over 400 years.<sup>54</sup> Estimates of the percent of the injected amount of thorium retained in the organs of greatest thorotrast deposition by different investigators are as follows: liver 71-73 percent; spleen 7-17 percent; bone marrow 6-10 percent. The most reasonable estimates at present of the average dose from 75 cc of thorotrast (Rads per week) are as follows: liver 1.5; spleen 2.5; bone marrow 0.3.<sup>30,54,57,97,108</sup>

Determination of the radiation dose to the tissue from thorotrast is a very difficult problem.<sup>54,95,97,104,105,108,121</sup> The extent of self absorption of the alpha particles in the thorotrast aggregates, the increasing size of the aggregate with increasing time after administration, and the state of radioactive equilibrium of the daughter elements of the thorium

series in the body are some of the more important factors which have to be taken into consideration in radiation dosimetry. Estimates of the radiation dose have been made by quantitative autoradiographic studies, radiochemical and spectrochemical determinations of thorium members of the thorium series in tissue specimens, excretion studies, and external measurement of the living patient. Estimates of the average radiation dose to the liver, by one or a combination of these methods, vary from about 1 to 9 rads per week following the deposition of 75 cc of thorotrast. The average accumulated dose to the liver, the primary organ of thorotrast deposition, in 50 years was calculated to be in the order of 3500 rads. Rothlat and Ward<sup>95,97</sup> found by quantitative autoradiography that the radiation dose to different parts of the spleen of a patient 11 years after administration varied by a factor of 20. Therefore, if we assume that the radiation dose in the liver of a patient varies by a factor of 20 after 50 years, then some areas of the liver may have received a total accumulative dose of about 700 rads, while others may have received as much as 14,000 rads based on the calculations of Rundo.<sup>108</sup>

There is a much greater variation of thorium in the bone marrow (0.1 to 77 mgm/gm ash tissue) than in the liver (125 to 420 mgm/gm of ash tissue) (see Table 1). The estimates of average accumulated radiation dose for the bone marrow will therefore be subject to greater fluctuation. If, however, we assume that the average accumulated radiation dose to the bone marrow is one tenth the average accumulated radiation dose to the liver, then the average accumulated radiation dose to the bone marrow would be in the order of 350 rads in 50 years.

##### B. Hematological Studies

###### 1. Anemias

Destruction of bone marrow might be expected in thorotrast

patients since it is one of the major organs of thorotrast deposition. Twelve cases have been reported in which patients died 3 to 17 years following thorotrast administration.<sup>15,26,48,57,62,71,75,78</sup> Since almost all of these were aplastic anemias it is possible that the thorotrast may have contributed to the anemias by destroying bone marrow. The difficulty of conclusively establishing a relationship between thorotrast deposition and hematological disorders is illustrated by the study of 222 patients by Backer.<sup>9,10</sup>

## 2. Leukemias

At present there has been no specific type of leukemia found in patients who previously received thorotrast. It would therefore seem that any correlation between leukemia and thorotrast administration will have to be made by showing an increased incidence in a large series of thorotrast patients compared to a control series of patients. Moloney<sup>79</sup> has recently made a review of the induction of leukemia in man by irradiation. Only ten cases were found in which thorotrast had been given prior to the induction of leukemia. Adequate data were available in only 6 cases. The time between thorotrast administration and the occurrence of leukemia was  $12 \pm 7$  years in these six patients.<sup>38,46,57,81,125</sup>

## C. Bone

The thorium content of compact and cancellous bone shortly after thorotrast administration and many years after thorotrast administration was found to be very small<sup>54</sup> (see Table 1). Radiochemical analysis of the radium isotopes of the organs of greatest thorium deposition (i.e. liver, spleen, bone marrow) and bone were made to see if any significant transference of the radium isotopes to bone occurred<sup>67</sup> (see Table 2). These results indicate that only a minute fraction of the

long-lived radium isotope Ra-228 as well as Th-232 are present in the skeleton either shortly after thorotrast administration or after long periods of deposition. Since the analyses were made several months after death no attempt was made to estimate the radiation dose to bone, because of the decay of the short-lived 3.6 day radium isotope, Ra-224. (See Figure 1).

Autoradiographic studies have given further evidence that only minute amounts of the two long-lived daughters of the thorium decay series (mesothorium (Ra-228) and radiothorium (Th-228)) are present in or transferred to bone. Autoradiographs of bone sections given long exposures (up to two years) showed that although bone shows a higher activity than natural background, the activity was minute as compared to the activity in the liver, spleen and bone marrow.<sup>6</sup>

It is possible that if Ra-224 is transferred to bone after being produced in the liver and spleen, then the skeleton would have to be considered as a primary organ with regard to the radiation dose from thorotrast, as the remaining six daughter radioelements of the thorium decay series have half-lives in the order of seconds to minutes, with the exception of Pb-212 which has a half life of 10.6 hours.

A recent report (1957) of preliminary calculations has been made of the possible skeletal burden of activity of a patient with 4 grams of thorium.<sup>91</sup> These authors estimate an alpha energy absorption by the skeleton equal to 40 to 100 percent of that absorbed by the skeleton of a patient with 0.1 micrograms of radium, the present permissible level.

Minor skeletal irregularities were found on skeletal survey of these patients and the preliminary results were published in 1954.<sup>64</sup> These skeletal roentgenographic findings are considered to be equivocal. We were able to demonstrate that some of the irregularities along the endosteal surface may



have been the result of the deposited thorotrast. Extensive examination of compact and cancellous bone was made on specimens obtained from two patients who died 17 days, (patient M.H.) and 19 years (patient A.D.) after thorotrast administration. Portions of the same specimens were used for histopathological studies, thorium analysis and radium isotope analysis (see Table 1). No quantitative difference was observed in the bone specimens when compared to bone specimens of comparable age groups. No histopathological changes characteristic of radium deposition were found.<sup>63</sup> (Bone specimens from a thorotrast patient supplied by Dr. Charles Johnansen of Copenhagen also failed to show histopathological changes characteristic of radium deposition). Moreover, Faber (1957) reported that skeletal surveys made on a larger and more unselected series of patients have failed to show similar skeletal irregularities.

Dental and dental roentgenographic examinations were made on 8 patients. In none of these patients were dental effects found which could be attributable to thorotrast.

If a relationship exists between the administration of thorotrast and the minor skeletal irregularities seen roentgenographically, it would be most likely from the radiation from the thorotrast aggregates in the bone marrow along the endosteum. One of the primary effects would probably be the result of decreased bone resorption along the endosteal surfaces as a result of damage to the osteoclasts. The minute radioactivity in bone most likely comes from the thorium deposited in the haversian canals, as no significant transfer of the radium isotopes from other parts of the body have been demonstrated at present. However, it is considered that the results of the studies to date give evidence which warrant further study.\*

#### D. Lungs

The lungs of four patients in the National Naval Medical Center study (see Table 1) were found to have an average of 200 mgm of thorium. It was estimated that the lungs would receive 0.06 rads per week, assuming homogenous thorium distribution throughout the lungs. Exhaled thorium was not taken into consideration in these calculations of the radiation dose.

Mitchell<sup>77</sup> has estimated that the thoron produced in the body of patients given 75 cc of thorotrast will give a radiation dose to the alveolar epithelium of lungs (approximately 150 gm of lung tissue) of 4 rads per week. This is based on the assumption that 5 percent of the thoron produced by thorium decay in the liver, spleen and bone marrow will be transferred by the blood stream to the lungs and exhaled.

The other available data on long-term pulmonary exposure from thorium are from a group of individuals employed in a thorium refinery.<sup>3</sup> There were 60 employees who had worked in direct exposure to thorium and thoron. One-half of these, 26 employees working at the time of the survey, had worked 10 years or more. No significant medical abnormalities were found which could be attributed to either thorium or thoron.

One of these workers died from a coronary occlusion after being employed for 10 years in the refinery. The alpha activity was 17 dpm in 6 mgm of ashed lung tissue. Based on the assumptions that the ashed weight of the lungs was 5 percent of the wet weight and that the total wet weight of the lungs was 1000 gms, the radiation dose to the lungs was estimated to be 0.2 rads per week. The total thorium content of the lungs was derived from the alpha activity in the ashed lung tissue. It was estimated that 110 mgm of thorium were homogeneously distributed throughout the lungs of this worker. The radiation

dose to the lungs from 110 mgm of thorium was estimated to be about 0.03 rads per week, based on the assumptions of Hursh *et al.*<sup>54</sup> or about one-seventh the radiation dose estimated by Albert *et al.*<sup>3</sup>

Evans<sup>7</sup> has estimated that about 0.2 percent of the thoron produced from mesothorium in the skeletons of the luminous dial workers is exhaled. It was calculated that 7 minutes is the time required for thoron atoms to move from the skeleton to be exhaled. This seven-minute travel time of thoron atoms produced in bone may be longer than would be necessary for the thoron atoms produced in the liver, spleen and bone marrow to be transferred to the lungs and exhaled. It is reasonable to expect that the percent of thoron exhaled will lie somewhere within the range of estimates made by Mitchell and Evans. If we assume that 1 percent of the thoron is exhaled then the radiation dose to the lungs of the patients with 75 cc of thorotrast would be about 1 rad per week based on Mitchell's estimates. Based on present information it would seem that the most reasonable estimates of radiation dose to the lungs of thorotrast patients who had received 75 cc of thorotrast would be about 1 rad per week.

### B. Carcinogenesis

Marked proliferation of connective tissue has been found around the extravasation of thorotrast in the neck and arms of some of the thorotrast patients. Considerable quantities of thorotrast are concentrated in relatively small volumes following injection into ducts, sinuses, etc. Nine tumors have been reported which have developed at the sites of local injection of thorotrast.<sup>17,19,37,49,85,102,103,109,130</sup> The tumors were found in the maxillary sinus, neck, breast, kidney, bronchus and eyelid. The time from administration until the occurrence

of the tumor ranged from 6 to 35 years. Extremely dense and hard indurated masses form around these areas of extravasation. Only one malignant tumor has been reported to arise in these soft tissue masses 6 years after thorotrast administration. A fibrous sarcoma developed in a patient at the site of injection in the cervical region. Following incomplete removal, the patient died 2 years later from generalized metastases.<sup>85</sup>

Another patient was found to have an adenocarcinoma of the head of the pancreas and a hypernephroma of the kidney.<sup>126</sup> Both carcinomata were in the region of a large deposit of thorotrast in the regional lymph nodes. The patient, age 70 years, had been given thorotrast for an arteriogram following intermittent claudication 13 years previously.

Abrahamson *et al.*<sup>1</sup> found a bilateral alveolar-cell carcinomata in the lungs of a patient who had received 75 cc of thorotrast 16 years prior to death. The author discusses the unique characteristics of the tumor and suggests that a relationship might exist between the presence of thorotrast and the induction of the neoplasm.

Twenty cases of primary hepatic tumors have been reported in patients who had been given thorotrast. Ten of these cases had either carcinoma of the liver or bile ducts.<sup>12,31,33,40,47,76,80,82,94,117</sup> Five of the twenty patients were given thorotrast for outlining the liver and spleen. In most of these cases thorotrast was given in attempts to diagnose hepatic disease. The contribution of cirrhosis resulting from hepatic disease would have to be taken into consideration in the evaluation of the cause of tumor induction. The frequency of primary hepatocellular and cholangiocellular tumors reported by Lunseth<sup>69</sup> is 0.33 percent of 26,410 autopsies performed at the Cook County Hospital between 1919 and 1950. The incidence of these tumors increased in the older age groups, therefore adequate control studies would be necessary to conclusively

establish a relationship between thorotrast administration and hepatocellular and cholangiocellular tumors.

The most significant finding in regard to tumor induction in man are neoplasms of the liver of mesodermal origin. Nine cases have been reported.<sup>27,35,50,51,68,71,84,92,120</sup> One<sup>113,115</sup> and presumably two hepatic tumors of mesodermal origin in this series of 35 cases, the experimental production of similar tumors in animals Johansen<sup>56,58</sup> Guimaraes, Lamerton, and Christensen,<sup>22,41,42</sup> Swarm,<sup>115</sup> Zeihofer and Speiser<sup>129</sup> is considered to be sufficient evidence to establish a relationship between thorotrast administration and tumor induction in man. Based on the present available information it would appear that an almost thorotrast specific tumor is developing. Stout<sup>114</sup> reports that these tumors are extremely rare. In 1956 Baker *et al.*<sup>11</sup> found only 25 cases of primary hepatic tumors of mesodermal origin in a review of the literature.

The estimated accumulated radiation dose to the liver in the thorotrast patients who developed Kupfer cell sarcomas of the liver was compared with the estimated accumulated radiation dose to the skeleton in the radium patients who developed sarcomas. The mean latent period in the five radium patients was  $23 \pm 4$  years.<sup>63</sup> The mean accumulated radiation dose in the five patients was estimated to be in the order of 4000 rads. The lowest estimated accumulated radiation dose to bone to induce a tumor was in the order of 1000 rads. The mean latent period in 8 of the 10 thorotrast patients with reticulo-sarcomas was  $15 \pm 7$  years, and the mean estimated accumulated radiation dose in 15 years was in the order of 1000 rads based on the estimates of Rundo,<sup>108</sup> and 1,500 based on the estimates of Hersh *et al.*<sup>54</sup> The average accumulated radiation dose to the liver of the patient who developed a tumor 3 years after the administration of 20 cc of thorotrast was estimated to be about

The question of the induction of reticulo-sarcomas of the liver by thorotrast will have to be re-evaluated as a result of a recent report of the occurrence of 3 similar hepatic tumors in 25 patients with chronic arsenic poisoning reported by Roth.<sup>98</sup> This report raises the question of the contribution of the presence of thorium, as well as the radiation from the decay of the daughter products of the thorium decay series, to the production of the tumors. Are these rare hepatic tumors in thorotrast patients radiation induced, or chemically induced, or a combination of chemical and radiation effects?

#### F. Clinical Follow-Up Studies

In 1942 a 10 year follow-up study of 286 patients given thorotrast was carried out by Yater and Coe.<sup>128</sup> It was found that 189 patients were dead, and 67 patients were unable to be located. There were no deleterious effects which could be attributed to thorotrast administration noted in the 30 patients examined. The list of patients of Yater and Coe was used in the location of some of the patients in these studies. Results of the clinical examination and laboratory findings of the study of Yater and Coe are given in Tables 2 and 3, along with the clinical examination and laboratory findings of this study.

A summary of the pertinent results of the principle thorotrast follow-up studies made over the past 30 years is given in Table 8. In the earlier studies no deleterious effects attributable to thorotrast could be found. Recent studies, however, show that local and general effects from thorotrast are beginning to occur. The four follow-up studies published recently illustrate the need for evaluation of large unbiased groups of patients to obtain a true clinical picture of the late effects of thorotrast. For example, the results of the study of Fruhling *et al.*<sup>36</sup> would seem to indicate that the late

deleterious effects from thorotrast are more severe than the study of Johansen, Backer, Rundo and Faber<sup>9,10,30,57,104</sup> and the study of Barrett and MacRay<sup>14</sup> would indicate. These recent follow-up studies indicate that the number of deleterious effects which can be detected by present methods of clinical evaluation and specifically attributed to thorotrast have been small. However, these studies demonstrate the inadequacy of our present clinical methods for detecting the deleterious effects of thorotrast. It is evident from pathological studies that considerable destruction has occurred in some of the organs in which thorotrast is deposited; yet, the clinical methods now available cannot properly evaluate the reduction in function caused by the destruction of the parachyma of the involved organs. For example, it is well known that clinical tests now available cannot detect abnormalities until a major part of the liver is destroyed. The bromsulphalein test is one of the most widely used clinical tests for the detection of damage from diffuse and chronic liver disease. Lichtmann<sup>62</sup> in his discussion of hepatic function tests states that the test is most likely to yield positive results where liver damage is diffuse and extensive (e.g., portal cirrhosis, biliary cirrhosis). The inadequacies inherent in our present methods of clinical evaluation apply not only to the evaluation of the thorotrast patients, but to the clinical effects of radiation in general. The inadequacy of our criteria for determining our present maximum permissible concentrations for radioelements and radiation in general is primarily the result of this lack of sensitivity of clinical tests to detect radiation damage. In most instances, we do not have at present satisfactory methods for determining the extent of reduction of organ function before the tests become positive. Moreover, the combined effects of thorotrast and intercurrent disease processes may act synergistically to

## SUMMARY AND CONCLUSIONS

1. The status of 35 patients who received thorotrast has been determined. There were relatively few deleterious effects directly attributable to thorotrast in these patients. The reports of the deleterious effects of thorotrast, since its first use in 1928, have been very small.
2. The occurrence of one, and presumably two, rare hepatic tumors of mesodermal origin in this series of 35 patients, and the reports of 9 additional tumors in the literature indicates that a relationship exists between thorotrast administration and hepatic tumor induction in man. It would seem that these hepatic tumors will emerge as the predominant tumor in thorotrast patients, as bone tumors have emerged as the predominant tumor in the luminous dial workers and people who received radium medically. The mean accumulated radiation dose to the liver in eight of these patients during the 15 year latent period was estimated to be in the order of 1000 rads. The lowest estimated accumulated dose of a patient who developed a hepatic tumor was in the order of 100 rads.
3. The question of whether the tumor induction in the thorotrast patients is the result of the presence of thorium, a result of radiation from the thorium decay series, or a combination of both must, in the last analysis, await a better understanding of chemical and radiation carcinogenesis. Similar tumors have been found in vineyard workers with chronic arsenic poisoning.

4. The combined microscopic, laboratory, and clinical studies have demonstrated the inadequacy of our present clinical and laboratory methods for detecting the deleterious effects of thorotrast as well as radiation in general. The spleens of some patients were almost completely destroyed, yet no means

are presently available to evaluate the effects of this destruction.

5. The mean age of 13 of the 35 patients who have died was 62 years. Because of the small number of patients and the inability to evaluate the contribution of the disease process, no attempt was made to determine if life span shortening was caused by thorotrast. However, the marked destruction of organs which is undetected by our present means of examination suggests that reduction in organ function may contribute to a reduction in life span. Moreover, a more specific mode of evaluation of life span shortening might be accomplished by the evaluation of the contribution of the effects of reduced organ function.

6. One of the great difficulties in the proper evaluation of clinical changes produced by small amounts of radiation is the determination of the validity of results. Since thorotrast was widely used in the United States, coordinated follow-up studies in medical centers on a nation-wide basis would be an effective means of obtaining information about the effects of thorotrast on hundreds of patients. In addition, the national organization of a follow-up study would permit the incorporation of similar studies within its framework. Furthermore, the availability of a large source of clinical material should facilitate the study of the mechanism of radiation induced somatic, neoplastic and genetic changes in man.\*

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\* Preliminary discussions concerning a national follow-up study have been held with the Medical Sciences Division of the National Research Council, the U.S. Public Health Service, U.S. Atomic Energy Commission, the Veteran Administration and the Medical Department of the United

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TABLE 1

THORIUM DISTRIBUTION\*  
(mgm thorium per gm of ashed tissue)

| Tissue               | Patient M.H.+<br>72 cc thorotrast<br>(retained 17 days)                                | Patient Y.C.++<br>60 cc thorotrast<br>(retained 49 days)  | Patient L.V.<br>40 and possibly<br>60 cc of thorotrast<br>(retained 10 years) | Patient A.D.<br>75 cc thorotrast<br>(retained 19 years)                            |
|----------------------|----------------------------------------------------------------------------------------|-----------------------------------------------------------|-------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| Aorta                |                                                                                        |                                                           |                                                                               |                                                                                    |
| Adrenal              | 55.0                                                                                   | A. 75.0<br>B. 42.0                                        | 2.3<br>0.9                                                                    |                                                                                    |
| Bone<br>(cancellous) | A. Dist. femur<br>B. Prox. tibia<br>0.31                                               |                                                           |                                                                               |                                                                                    |
| Bone<br>(compact)    | A. Ilium<br>B. Prox. femur<br>C. Dist. femur<br>D. Mid-tibia<br>0.20<br>0.030<br>0.008 |                                                           |                                                                               | A. Tibia 0.40<br>B. Mid-tibia 0.003<br>C. Femur 2.5<br>D. Mid-femur 0.03           |
| Bone<br>Marrow       | A. Femur<br>B. Mid-femur<br>C. Dist. femur<br>D. Tibia<br>42.4<br>36.7<br>12.1<br>0.10 |                                                           |                                                                               | A. Mid-tibia 7.5<br>B. Dist. tibia 1.3<br>C. Mid-femur 77.0<br>D. Dist. femur 11.4 |
| Brain                |                                                                                        | 1.2                                                       |                                                                               |                                                                                    |
| Heart                | 2.9                                                                                    | 6.9                                                       | 2.3                                                                           | 2.3                                                                                |
| Intestine            | 15.0                                                                                   |                                                           |                                                                               | 1.1                                                                                |
| Kidney               | 30.0                                                                                   |                                                           |                                                                               | 2.9                                                                                |
| Liver                | 157.0                                                                                  | A. Central 320.0<br>B. Peripheral 420.0                   | A. 250.0<br>B. 380.0                                                          | 125.0                                                                              |
| Lung                 | 11.3                                                                                   | A. Proximal 24.0<br>B. Central 16.0<br>C. Peripheral 14.0 | A. 4.4<br>B. 7.8                                                              |                                                                                    |
| Muscle               | 0.05                                                                                   |                                                           |                                                                               | 1.6                                                                                |
| Pancreas             | 16.8                                                                                   |                                                           | 4.0                                                                           |                                                                                    |
| Rib                  |                                                                                        |                                                           |                                                                               | 10.9                                                                               |
| Spleen               | 357.0                                                                                  | A. 61.0<br>B. 57.0                                        | A. 300.0<br>B. 210.0                                                          | A. 3900.0 **<br>B. 2700.0                                                          |
| Sternum              | 2.4                                                                                    |                                                           |                                                                               | 18.2                                                                               |
| Thyroid              | 4.0                                                                                    |                                                           |                                                                               | 24.0                                                                               |
| Vertebrae            |                                                                                        |                                                           | 131.0                                                                         | 12.6                                                                               |

\* See Table 5 for clinical history and pertinent findings on these patients.

+ This patient had a carcinoma of the pancreas.

++ This patient had a carcinoma of the liver at the time thorotrast was administered.

TABLE 2

THORIUM AND RADIUM ISOTOPE DISTRIBUTION  
FOLLOWING THOROTRAST ADMINISTRATION

| THORIUM *                               |                               |                   | RADIUM ISOTOPES **                                             |                               |
|-----------------------------------------|-------------------------------|-------------------|----------------------------------------------------------------|-------------------------------|
| (Mgm. Thorium per Gram)<br>(Ash Weight) |                               |                   | Counts per minute per Gram<br>(Alpha-Activity)<br>(Ash Weight) |                               |
| Patient<br>M.H.<br>(17 days)            | Patient<br>A.D.<br>(19 years) |                   | Patient<br>M.H.<br>(17 days)                                   | Patient<br>A.D.<br>(19 years) |
| 11.3                                    | 46.3                          | Lung              | 908                                                            | 3,750                         |
| 137.0                                   | 125.0                         | Liver             | 8,829                                                          | 12,467                        |
| 357.0                                   | 3,900.0                       | Spleen            | 12,878                                                         | 71,458                        |
| 42.4                                    | 77.0                          | Marrow<br>(Femur) | 1,638                                                          | 1,046                         |
| 0.03                                    | 0.03                          | Shaft<br>(Femur)  | 14                                                             | 24                            |
| 0.008                                   | 0.003                         | Shaft<br>(Tibia)  | 4                                                              | 8                             |

(Patient M.H. received 72 cc of thorotrast and Patient A.D. received 75 cc of thorotrast).

\* Harsh, Stedman, Looney & Colodzin (1957)<sup>54</sup>

\*\* Looney & Colodzin (1955)<sup>67</sup>

TABLE 3

AGE (1954) AND PERIOD OF THOROTRAST RETENTION

| Group I                                                                         |                       |                              | Group II                                                                        |                       |                              |
|---------------------------------------------------------------------------------|-----------------------|------------------------------|---------------------------------------------------------------------------------|-----------------------|------------------------------|
| Patients who had Procedures usually requiring from 15 cc to 25 cc of thorotrast |                       |                              | Patients who had Procedures usually requiring from 60 cc to 75 cc of thorotrast |                       |                              |
| Initials                                                                        | Age - 1954<br>(years) | Time of Retention<br>(years) | Initials                                                                        | Age - 1954<br>(years) | Time of Retention<br>(years) |
| T.A.                                                                            | 47                    | 8                            | R.B.                                                                            | 72                    | 14                           |
| B.B.                                                                            | 34                    | 9                            | T.C.                                                                            | 43                    | (49 days)                    |
| P.B.                                                                            | 50                    | 9                            | M.C.                                                                            | 82                    | 23                           |
| F.B.                                                                            | 51                    | 16                           | A.D.                                                                            | 30                    | 20                           |
| L.C.                                                                            | ( 55)                 | 23                           | A.D.                                                                            | 85                    | 19                           |
| B.K.                                                                            | 26                    | 22                           | M.G.                                                                            | 40                    | 14                           |
| C.P.                                                                            | 32                    | 14                           | M.H.                                                                            | 58                    | (17 days)                    |
| M.P.                                                                            | 26                    | 9                            | S.L.                                                                            | 40                    | 10                           |
| B.R.                                                                            | ( 35)                 | 18                           | L.W.                                                                            | 65                    | 9                            |
| J.R.                                                                            | 27                    | 22                           | M.McB.                                                                          | 38                    | 8                            |
| E.S.                                                                            | 44                    | 10                           | W.M.                                                                            | 86                    | 15                           |
| L.S.                                                                            | 31                    | 22                           | M.R.                                                                            | 51                    | 22                           |
| A.W.                                                                            | 57                    | 18                           | F.S.                                                                            | 56                    | 7                            |
| V.W.                                                                            | 44                    | 18                           | E.S.                                                                            | 63                    | 22                           |
| F.S.                                                                            | 56                    |                              | A.T.                                                                            | 35                    | (Given 8-20-54)              |
|                                                                                 |                       |                              | L.W.                                                                            | 59                    | 19                           |
|                                                                                 |                       |                              | C.W.                                                                            | 48                    | 1                            |
|                                                                                 |                       |                              | J.H.                                                                            | 77                    |                              |
|                                                                                 |                       |                              | D.V.                                                                            | 69                    |                              |
|                                                                                 |                       |                              | C.C.                                                                            | 64                    |                              |
| Mean                                                                            | 44 ± 11               | 15.6 ± 5.7                   | Mean                                                                            | 58 ± 15.7             | 14.5 ± 6.8                   |

Data in parentheses omitted in calculation of mean values.

**GROUP I**  
**PROCEDURES WHICH USUALLY REQUIRED**  
**FROM 15-20% OF THE ORGANS**

Table 4--Continued

**GROUP I**  
**PROCEDURES WHICH USUALLY REQUIRED**  
**FROM 12-15% OF THROTFAST**

|                             |                                                    |                             |                                                                                   |                                                |                                                                                                                                                                                                                                      |
|-----------------------------|----------------------------------------------------|-----------------------------|-----------------------------------------------------------------------------------|------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| R. E.<br>2/26/70            | Biological<br>system<br>Chondromesenchymal<br>bone | 1928<br>52 yrs.<br>Age - 58 | 11/16/70<br>neg.                                                                  | 2/26/73<br>neg.                                | Increase in density of liver and spleen. General increase. Fine granular cells and some have concentric of trabecular pattern. Thickening of capsule at base of lobes.                                                               |
| C. P.<br>2/23/70<br>7/23/74 | Surrounding<br>liver remnant<br>Pressure           | 1944<br>14 yrs.<br>Age - 52 | 5/19/73<br>50 met.<br>20%                                                         | 7/18/74<br>4.7%                                | Deposits of lipofuscin in connective tissue. Increase in density of liver and spleen. Accumulated trabecular pattern of connective tissue.                                                                                           |
| M. P.<br>5/7/76             | Cerebral<br>Anastom.                               | 1945<br>9 yrs.<br>Age - 59  | 5/7/74<br>1.4%<br>Total Prot.<br>Cap. Pres.<br>Plas.<br>B. 0<br>4.4 d/dm.<br>B. 4 | 5/7/74<br>10%<br>B. 0<br>4.4 d/dm.<br>B. 4     | Increase in density of neck - more so left. Some increase in density of liver and spleen. Some increase in trabecular pattern with longitudinal trabeculae. Some trabecular pattern attributable to the mid-lobular atrophy.         |
| B. E.<br>5/7/73<br>8/17/74  | Epiglottis                                         | 1900<br>12 yrs.<br>Age - 10 | 5/7/73<br>1.9mm.<br>WBAC 3.37%<br>lymph 20%                                       | 8/17/74<br>1.1.9mm.<br>WBAC 3.37%<br>lymph 20% | Increase in density right side of neck and upper mediastinum. Fine granular cells in density of spleen. Right cross-section of trabecular pattern of connective tissue. Some trabeculae have a faintly trabecular appearance.        |
|                             |                                                    |                             |                                                                                   |                                                | Marked atrophy and nodules on the right side of neck. General atrophy of patient fat.                                                                                                                                                |
|                             |                                                    |                             |                                                                                   |                                                | Diagnosis of basal tumor 1923.<br>Increase in trabecular pressure<br>age right side of hepatopig. 1944<br>constriction of connective tissue<br>from hepatopig-lymphatics of left<br>renal cord and fibrosis of connective<br>tissue. |
|                             |                                                    |                             |                                                                                   |                                                | 1949 - atrophy of connective tissue<br>thrombus given and connective tissue<br>lymphatic. Right side hepatopig. 1949<br>Trabecular pressure - neck and renal<br>connective tissue. 1949 - second<br>constriction.                    |



Table 4--Continued

GROUP 1  
PROCEDURES WHICH USUALLY REQUIRED  
FROM 15-MIN OF THOROTRAST

|                             |                                            |                             |                                                      |                                                       |                                                                                                                                                                                                                                       |
|-----------------------------|--------------------------------------------|-----------------------------|------------------------------------------------------|-------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| J. B.<br>6/6/53             | Spleen<br>Enlargement<br>14x.              | 1953<br>20 yrs.<br>Age - 44 | S. B. P.<br>Cap. Pres.<br>20.                        | 13/3/53<br>Reg.<br>3.95<br>3.7 (others.)<br>16. Agam. | 1953 - bleeding from O.I. tract. 1953 - enlargement of spleen and liver - megakaryocytic particles made. Liver and spleen returned to normal size. Enlargement again in 1953 - splenomegaly. Spleen consistently negative since 1953. |
| B. S.<br>6/21/53<br>7/12/54 | Possible Breast<br>Tumor                   | 1954<br>30 yrs.<br>Age - 44 | B. S. P.<br>Total Pres.<br>20                        | 6/21/53<br>Reg.<br>3.95<br>13. Agam.                  | In 1953 beginning weakness on left side. In 1954 cerebral arteriogram. 1954 operated at National Institute of Health. Old brain hemorrhage found. Possible ventral cord paravertebral thrombus.                                       |
| J. B.<br>Dead 1953          | Raynaud's<br>Disease                       | Age - 44 (1953)             | Reg. 1953<br>S. B. P. 40.95<br>Cap. Pres.<br>20. Ag. | 6/21/53<br>Reg.<br>3.95<br>13. Agam.                  | Thrombus found at autopsy. 1954 Raynaud's disease. 1955 spleen & lymphatic nodes. Liver section - no clear paravertebral thrombus with pigment material. Arteriolethrombi & microthrombi.                                             |
| L. S.<br>3/19/53            | Possible<br>Spleen<br>Enlargement<br>6 cc. | 1953<br>33 yrs.<br>Age - 51 |                                                      |                                                       | Also occurred. Thorotrast given for possible rupture. No significant ill-effects since.                                                                                                                                               |
| A. W.<br>10/26/50           | Raynaud's<br>Disease<br>20 cc.             | 1950<br>33 yrs.<br>Age - 37 |                                                      |                                                       | Vascular disturbance since 1951. Thorotrast in 1950. Thorotrast soluble removed in 1950 from right arm. 1954 made splenectomy again. 1953 - liver biopsy - nodular fibrotic changes.                                                  |
| V. W.<br>2/12/53<br>3/17/54 | Normal<br>picture                          | 1953<br>38 yrs.<br>Age - 44 | S. B. P.<br>Lymph                                    | 3/12/53<br>1.95<br>5.55                               | Given for normal arteriogram. January 1953 - normal activity since recovery.                                                                                                                                                          |

Table 5

GROUP 2  
PROCEDURES WHICH USUALLY REQUIRED  
FROM 60-Min OF THOROTRAST

| Patient<br>Date of<br>Examination    | Reason for<br>giving Thorotrast<br>Amount | Time of Am.<br>Biopsy<br>Years   | Periodic<br>Laboratory and Rheumatological Findings |                               |                               |                               | Sanguinofluoric Changes                                                                                                                                                               | Pertinent Clinical Data                                                                                                                                                                                                                         |
|--------------------------------------|-------------------------------------------|----------------------------------|-----------------------------------------------------|-------------------------------|-------------------------------|-------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                      |                                           |                                  | Test                                                | Date                          | Value                         | Range                         |                                                                                                                                                                                       |                                                                                                                                                                                                                                                 |
| B. S.<br>3.5.54<br>Dead 1954         | Children                                  | 1957<br>14 yrs.<br>Age - 15 yrs. | WBC<br>RBC<br>Hct. rate                             | 3.5.54<br>12.10.53<br>3.15    | 12.10.53<br>3.15              | 12.10.53<br>3.15              | Generalized coarsening of trabecular pattern - especially ribs and ilia. Thickening of skin in midline 1.3. Increased density of liver and spleen.                                    | Magnified - pneumonia 1957. Thorotrast considered to have been given at this time BP 110/90. Liver given before radii margin in 1953 and 1954 - Dead March 1954 - heart attack.                                                                 |
| Y. C.<br>Dead 1955                   | Raynaud's<br>Disease                      | 1955<br>48 days<br>Age 45 (1955) | WBC<br>RBC<br>Hct. rate                             | 1955<br>15.000<br>4.000<br>27 | 1955<br>32.000<br>9.100<br>71 | 1955<br>32.000<br>9.100<br>71 | Diagnosis of primary Raynaud's made. Thorotrast given to determine if microthrombi were present in other parts of liver.                                                              | 1955 - Enlarged spleen and elevated white blood count. 1955 diagnosis of chronic Raynaud's - 3 ray treatments. Thorotrast given. Microthrombi in arterial system from extramedullary thrombus. Used 1954 from cerebral hemorrhage - no autopsy. |
| M. C.<br>1951<br>30 yrs.<br>Age - 52 | Enlarged<br>Spleen<br>(Lymphoma)          | 1951<br>30 yrs.<br>Age - 52      | WBC<br>RBC<br>Hct. rate                             | 1951<br>15.000<br>4.000<br>27 | 1951<br>32.000<br>9.100<br>71 | 1951<br>32.000<br>9.100<br>71 | Microthrombi in spleen in 1951. Spleen gradually enlarged - removed in 1951. Thorotrast probably given before autopsy. Used 1954 primary Raynaud's of liver with wide spread nodules. | 1951 - Enlarged spleen and elevated white blood count. 1951 diagnosis of chronic Raynaud's - 3 ray treatments. Thorotrast given. Microthrombi in arterial system from extramedullary thrombus. Used 1954 from cerebral hemorrhage - no autopsy. |
| A. D.<br>Dead 1953                   | Enlarged<br>Spleen<br>(Lymphoma)          | 1953<br>30 yrs.<br>Age - 52      | WBC<br>RBC<br>Hct. rate                             | 1953<br>15.000<br>4.000<br>27 | 1953<br>32.000<br>9.100<br>71 | 1953<br>32.000<br>9.100<br>71 | Microthrombi in spleen in 1953. Spleen gradually enlarged - removed in 1953. Thorotrast probably given before autopsy. Used 1954 primary Raynaud's of liver with wide spread nodules. | 1953 - Enlarged spleen and elevated white blood count. 1953 diagnosis of chronic Raynaud's - 3 ray treatments. Thorotrast given. Microthrombi in arterial system from extramedullary thrombus. Used 1954 from cerebral hemorrhage - no autopsy. |
| A. D.<br>Dead 1953                   | Enlarged<br>Spleen<br>(Lymphoma)          | 1953<br>30 yrs.<br>Age - 52      | WBC<br>RBC<br>Hct. rate                             | 1953<br>15.000<br>4.000<br>27 | 1953<br>32.000<br>9.100<br>71 | 1953<br>32.000<br>9.100<br>71 | Microthrombi in spleen in 1953. Spleen gradually enlarged - removed in 1953. Thorotrast probably given before autopsy. Used 1954 primary Raynaud's of liver with wide spread nodules. | 1953 - Enlarged spleen and elevated white blood count. 1953 diagnosis of chronic Raynaud's - 3 ray treatments. Thorotrast given. Microthrombi in arterial system from extramedullary thrombus. Used 1954 from cerebral hemorrhage - no autopsy. |
| M. C.<br>1951<br>30 yrs.<br>Age - 52 | Enlarged<br>Spleen<br>(Lymphoma)          | 1951<br>30 yrs.<br>Age - 52      | WBC<br>RBC<br>Hct. rate                             | 1951<br>15.000<br>4.000<br>27 | 1951<br>32.000<br>9.100<br>71 | 1951<br>32.000<br>9.100<br>71 | Microthrombi in spleen in 1951. Spleen gradually enlarged - removed in 1951. Thorotrast probably given before autopsy. Used 1954 primary Raynaud's of liver with wide spread nodules. | 1951 - Enlarged spleen and elevated white blood count. 1951 diagnosis of chronic Raynaud's - 3 ray treatments. Thorotrast given. Microthrombi in arterial system from extramedullary thrombus. Used 1954 from cerebral hemorrhage - no autopsy. |

Table 5—Continued

GROUP B  
PROCEDURES WHICH USUALLY REQUIRED  
FROM 60-70% OF THYROTAST

|                             |                                     |                                   |                                                                                                                        |                                                          |                                                                                                                                                                                         |
|-----------------------------|-------------------------------------|-----------------------------------|------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| M. H.<br>Died 1963          | Cholelithiasis<br>Pancreatic<br>Tic | 1963<br>17 days<br>Apr 26/1963    | 1963 - 1967<br>Anatomical Abnormalities: gallbladder present,<br>Liver Indurated 4 - Cap. fib.<br>Lymphatic (1963) - 0 | In reduced density of liver and spleen<br>Enlarged liver | Palpable nodules of spleen<br>Thyroid gland given to autopsy<br>by Japanese cause of death. A.<br>and from circulation of gallbladder<br>17 25 33                                       |
| E. L.<br>Died 1967          | Enlargement of<br>Cyst of Liver     | 1957<br>18 yrs<br>Apr 26/1947     | 1948 - 1967<br>Anatomical Abnormalities: gallbladder present,<br>Liver Indurated 4 - Cap. fib.<br>Lymphatic (1963) - 0 | Increased density of liver and spleen<br>Enlarged liver  | Autopsy in 1958. Spleen for<br>Thyroid gland given to autopsy in 1967.<br>Thyroid gland given to autopsy in 1968<br>with Japanese Indurated Gallbladder<br>Lymphatic current. Died 1967 |
| L. M.<br>Died 1963          | Enlarged<br>Liver &<br>Spleen       | 1964<br>9 yrs<br>Apr 26/1963      | 1964 - 1967<br>Anatomical Abnormalities: gallbladder present,<br>Liver Indurated 4 - Cap. fib.<br>Lymphatic (1963) - 0 | Increased density of liver and spleen<br>Enlarged liver  | 1968 operations for gallbladder<br>1958 Indurated 1964 gallbladder cause<br>found in pancreas. 1964 removed<br>gallbladder - cauterized. Died 12 5 33                                   |
| M. M. B.<br>Died 1963       | Enlarged<br>Liver                   | 1964<br>9 yrs<br>Apr 26/1963      | 1964 - 1967<br>Anatomical Abnormalities: gallbladder present,<br>Liver Indurated 4 - Cap. fib.<br>Lymphatic (1963) - 0 | Increased density of liver and spleen<br>Enlarged liver  | 1968 operations for gallbladder<br>1958 Indurated 1964 gallbladder cause<br>found in pancreas. 1964 removed<br>gallbladder - cauterized. Died 12 5 33                                   |
| W. H.<br>1/19/53<br>1/19/54 | Enlarged<br>Liver &<br>Spleen       | 1953-1960<br>14-18 yrs.<br>Apr 26 | 1953 - 1967<br>Anatomical Abnormalities: gallbladder present,<br>Liver Indurated 4 - Cap. fib.<br>Lymphatic (1963) - 0 | Increased density of liver and spleen<br>Enlarged liver  | 1968 operations for gallbladder<br>1958 Indurated 1964 gallbladder cause<br>found in pancreas. 1964 removed<br>gallbladder - cauterized. Died 12 5 33                                   |
| M. B.<br>1/19/53<br>1/19/54 | Enlarged<br>Liver &<br>Spleen       | 1953-1960<br>14-18 yrs.<br>Apr 26 | 1953 - 1967<br>Anatomical Abnormalities: gallbladder present,<br>Liver Indurated 4 - Cap. fib.<br>Lymphatic (1963) - 0 | Increased density of liver and spleen<br>Enlarged liver  | 1968 operations for gallbladder<br>1958 Indurated 1964 gallbladder cause<br>found in pancreas. 1964 removed<br>gallbladder - cauterized. Died 12 5 33                                   |
| E. L.<br>1/19/53<br>1/19/54 | Enlarged<br>Liver &<br>Spleen       | 1953-1960<br>14-18 yrs.<br>Apr 26 | 1953 - 1967<br>Anatomical Abnormalities: gallbladder present,<br>Liver Indurated 4 - Cap. fib.<br>Lymphatic (1963) - 0 | Increased density of liver and spleen<br>Enlarged liver  | 1968 operations for gallbladder<br>1958 Indurated 1964 gallbladder cause<br>found in pancreas. 1964 removed<br>gallbladder - cauterized. Died 12 5 33                                   |

Table 5—Continued

GROUP B  
PROCEDURES WHICH USUALLY REQUIRED  
FROM 60-70% OF THYROTAST

|                             |                               |                                   |                                                                                                                        |                                                         |                                                                                                                                                                                         |
|-----------------------------|-------------------------------|-----------------------------------|------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| F. B.<br>1/19/53<br>1/19/54 | Enlarged<br>Liver &<br>Spleen | 1953-1960<br>14-18 yrs.<br>Apr 26 | 1953 - 1967<br>Anatomical Abnormalities: gallbladder present,<br>Liver Indurated 4 - Cap. fib.<br>Lymphatic (1963) - 0 | Increased density of liver and spleen<br>Enlarged liver | Autopsy in 1958. Spleen for<br>Thyroid gland given to autopsy in 1967.<br>Thyroid gland given to autopsy in 1968<br>with Japanese Indurated Gallbladder<br>Lymphatic current. Died 1967 |
| A. T.<br>1/19/53<br>1/19/54 | Enlarged<br>Liver &<br>Spleen | 1953-1960<br>14-18 yrs.<br>Apr 26 | 1953 - 1967<br>Anatomical Abnormalities: gallbladder present,<br>Liver Indurated 4 - Cap. fib.<br>Lymphatic (1963) - 0 | Increased density of liver and spleen<br>Enlarged liver | Autopsy in 1958. Spleen for<br>Thyroid gland given to autopsy in 1967.<br>Thyroid gland given to autopsy in 1968<br>with Japanese Indurated Gallbladder<br>Lymphatic current. Died 1967 |
| L. W.<br>Died 1961          | Enlarged<br>Liver &<br>Spleen | 1953-1960<br>14-18 yrs.<br>Apr 26 | 1953 - 1967<br>Anatomical Abnormalities: gallbladder present,<br>Liver Indurated 4 - Cap. fib.<br>Lymphatic (1963) - 0 | Increased density of liver and spleen<br>Enlarged liver | Autopsy in 1958. Spleen for<br>Thyroid gland given to autopsy in 1967.<br>Thyroid gland given to autopsy in 1968<br>with Japanese Indurated Gallbladder<br>Lymphatic current. Died 1967 |
| C. W.<br>1/19/53<br>1/19/54 | Enlarged<br>Liver &<br>Spleen | 1953-1960<br>14-18 yrs.<br>Apr 26 | 1953 - 1967<br>Anatomical Abnormalities: gallbladder present,<br>Liver Indurated 4 - Cap. fib.<br>Lymphatic (1963) - 0 | Increased density of liver and spleen<br>Enlarged liver | Autopsy in 1958. Spleen for<br>Thyroid gland given to autopsy in 1967.<br>Thyroid gland given to autopsy in 1968<br>with Japanese Indurated Gallbladder<br>Lymphatic current. Died 1967 |
| C. W.<br>Died 1963          | Enlarged<br>Liver &<br>Spleen | 1953-1960<br>14-18 yrs.<br>Apr 26 | 1953 - 1967<br>Anatomical Abnormalities: gallbladder present,<br>Liver Indurated 4 - Cap. fib.<br>Lymphatic (1963) - 0 | Increased density of liver and spleen<br>Enlarged liver | Autopsy in 1958. Spleen for<br>Thyroid gland given to autopsy in 1967.<br>Thyroid gland given to autopsy in 1968<br>with Japanese Indurated Gallbladder<br>Lymphatic current. Died 1967 |
| J. H.<br>Died 1963          | Enlarged<br>Liver &<br>Spleen | 1953-1960<br>14-18 yrs.<br>Apr 26 | 1953 - 1967<br>Anatomical Abnormalities: gallbladder present,<br>Liver Indurated 4 - Cap. fib.<br>Lymphatic (1963) - 0 | Increased density of liver and spleen<br>Enlarged liver | Autopsy in 1958. Spleen for<br>Thyroid gland given to autopsy in 1967.<br>Thyroid gland given to autopsy in 1968<br>with Japanese Indurated Gallbladder<br>Lymphatic current. Died 1967 |
| W. C.<br>Died 1963          | Enlarged<br>Liver &<br>Spleen | 1953-1960<br>14-18 yrs.<br>Apr 26 | 1953 - 1967<br>Anatomical Abnormalities: gallbladder present,<br>Liver Indurated 4 - Cap. fib.<br>Lymphatic (1963) - 0 | Increased density of liver and spleen<br>Enlarged liver | Autopsy in 1958. Spleen for<br>Thyroid gland given to autopsy in 1967.<br>Thyroid gland given to autopsy in 1968<br>with Japanese Indurated Gallbladder<br>Lymphatic current. Died 1967 |

Table 6

| NAME  | DATE                           | D. & P.<br>Retention<br>(48 hrs.) | Direct<br>(mgm. per 100 cc.) | VDR<br>(mgm. per 100 cc.) | Total<br>Prost.   | Alb.<br>(mgm. per 100 cc.) | Glob.<br>(mgm. per 100 cc.) | Chol.<br>(mgm. per 100 cc.) | Esters<br>(Percent) | Alb. Phos.<br>(Bodansky)<br>(Units) | Thymol.<br>(MacLagan)<br>(Units) | Ceph.<br>Floc.<br>(48 hrs.) | Prothrombin<br>Time<br>(Sec.) |
|-------|--------------------------------|-----------------------------------|------------------------------|---------------------------|-------------------|----------------------------|-----------------------------|-----------------------------|---------------------|-------------------------------------|----------------------------------|-----------------------------|-------------------------------|
|       |                                |                                   |                              |                           |                   |                            |                             |                             |                     |                                     |                                  |                             |                               |
| T. A. | 2/10/53<br>3/7                 | 30<br>neg                         | .80                          | .17                       | 8.5               | 4.3                        | 2.3                         |                             |                     | 2.0                                 | 4                                | neg                         | 14 sec.                       |
| E. B. | 4/14/53<br>12/12/54<br>3/10/55 | 7.2<br>neg                        | .21<br>.13                   | .79<br>.31                | 7.1<br>8.2        | 5.3<br>4.7                 | 1.6<br>1.6                  | 190                         | 89%                 | 2.6<br>2.2                          | 3<br>2                           | neg                         | 15 sec.<br>21 sec.            |
| P. B. | 4/22/53<br>7/24/54<br>12/7/54  | neg<br>neg<br>neg                 | .19<br>.08<br>.09            | .31<br>.17<br>.37         | 5.3<br>8.3<br>8.8 | 4.1<br>4.7<br>4.1          | 1.2<br>1.6<br>1.7           | 275                         | 75%                 | 1.6<br>4.2<br>2.0                   | 2<br>1<br>1                      |                             | 20 sec.<br>13 sec.<br>13 sec. |
| F. B. | 5/15/53                        | neg                               | .32                          | .00                       | 9.9               | 5.6                        | 3.0                         |                             |                     | 2.2                                 | 2                                |                             | 14 sec.                       |
| L. C. | 10/7/54<br>11/16/              | neg                               |                              |                           | 8.3               | 4.3                        | 2.1                         | 170                         | 80%                 | 1.3                                 | 3                                | neg                         |                               |
| E. K. | 2/17/53                        | neg                               | .59                          | .83                       | 6.3               | 4.7                        | 1.6                         |                             |                     | 1.8                                 | 6                                |                             | 14 sec.                       |
| C. P. | 3/18/53<br>7/13/54             | neg<br>neg                        | .04<br>.04                   | .22<br>.22                | 8.1               | 5.2                        | 2.8                         | 280                         | 20%                 | 1.3                                 | 3                                |                             | 14 sec.<br>20 sec.            |
| M. P. | 8/7/54<br>3/7/55               | 1.0%<br>30%                       | .90                          | .37                       | 6.6               | 5.3                        | 2.2                         | 167                         | 70%                 | 2.0                                 | 2                                |                             | 14 sec.                       |
| E. B. | 9/17/54                        | neg                               | .16                          | .26                       | 8.3               | 4.6                        | 1.6                         | 176                         | 75%                 | 1.6                                 | 2                                | neg                         | 17                            |
| J. B. | 12/8/50<br>6/6/53              | neg<br>3.0%                       | .22<br>.22                   | .12                       | 8.3               | 4.3                        | 2.1                         | 190                         | 75%                 | 1.6                                 | 1                                |                             | 13                            |
| E. B. | 5/21/53<br>7/13/54             | neg<br>3.0                        |                              |                           | 6.7               | 3.6                        | 2.2                         |                             |                     | 2.6                                 | 1                                |                             | 13                            |
| L. B. | 2/19/53<br>11/29/54            | neg<br>neg                        | .04                          | .60                       | 6.3               | 4.2                        | 2.1                         | 167                         | 65%                 | 2.0                                 | 4                                |                             | 15 sec.                       |
| A. W. | 10/24/48                       |                                   |                              |                           |                   |                            |                             |                             |                     | 4.1                                 |                                  |                             |                               |
| W. W. | 1/15/53<br>12/9/54             | 1.6<br>neg                        | .04<br>.08                   | .40<br>.08                | 7.3<br>6.5        | 5.3<br>4.6                 | 2.0<br>2.0                  | 213<br>221                  | 60%<br>70%          | 1.6<br>2.3                          | 7<br>4                           | 7.1<br>neg                  | 15 sec.<br>13 sec.            |

Table 6 - Continued

|              |                                         |                           |                   |                   |                   |                   |                   |             |            |                   |             |            |                               |
|--------------|-----------------------------------------|---------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------|------------|-------------------|-------------|------------|-------------------------------|
| R. B.        | 2/2/54<br>3/24/53                       | 10.6<br>neg.              |                   |                   |                   |                   |                   |             |            |                   |             |            |                               |
| A. D.        | 6/52                                    |                           | 1.2               | .2                |                   |                   |                   |             |            |                   |             |            |                               |
| M. G.        | 2/19/53<br>8/5/54<br>3/19/55            | 20.6<br>.6<br>neg         | .08<br>.08<br>.09 | .45<br>.08<br>.17 | 9.3<br>8.6<br>9.7 | 4.2<br>4.6<br>4.7 | 2.0<br>1.7<br>2.0 | 240<br>240  | 65%<br>77% | 1.6<br>1.2<br>2.4 | 4<br>3<br>2 | neg<br>neg | 15 sec.<br>13 sec.<br>12 sec. |
| L. M.        | 11/19/53                                | 55%                       |                   |                   |                   |                   |                   |             |            |                   |             |            |                               |
| M. McI       | 11/48<br>13/48<br>13/53                 |                           |                   |                   |                   |                   |                   |             |            |                   |             |            |                               |
| W. M.        | 1/13/53<br>12/2/54                      | neg                       | .13<br>.37        | .62<br>.46        | 9.0<br>8.3        | 3.1<br>3.6        | 2.9<br>2.6        | 237<br>187  | 89%<br>76  | 2.0<br>2.2        | 3<br>2      | neg<br>neg | 14 sec.<br>14 sec.            |
| M. B.        | 3/13/48<br>3/19/53<br>7/29/54<br>3/8/55 | neg<br>neg<br>4.5%<br>54% | .22<br>.06        | .60<br>.63        | 8.5<br>8.7        | 2.7<br>3.7        | 2.8<br>3.8        | 175<br>243  | 75%<br>76% | 3.1<br>2.6        | 4<br>2      | neg<br>neg | 13 sec.                       |
| F. B.        | 3/9/53<br>3/17/53<br>3/27/54            | neg<br>12.4<br>2.6        | .18<br>.04        | .82<br>.16        | 6.3<br>7.1        | 4.4<br>4.7        | 1.9<br>2.4        |             |            | 3.0<br>2.2        | 1<br>1      | neg<br>neg | 16 sec.<br>14                 |
| E. B.        | 5/19/53                                 | neg                       |                   |                   |                   |                   |                   |             |            |                   |             |            | 14 sec.                       |
| A. T.        | 4/20/54<br>7/29/54                      | neg<br>1.0%               | .13<br>.08        | .89<br>.37        | 7.6<br>6.3        | 6.3<br>4.4        | 2.6<br>1.9        | 180<br>167  | 71<br>74   | 1.2<br>1.6        | 2           | neg        | 14 sec.<br>13                 |
| C. W.        | 3/14/55                                 | 3%                        |                   |                   |                   |                   |                   |             |            |                   |             |            | 14-16 sec.                    |
| Normal Value |                                         | 9%                        | 5-8               | 0-5               | 6-8               | 3.6-<br>5.6       | 1.2-<br>2.3       | 140-<br>220 | 60-80%     | 1.6-4             | 3-5.5       |            |                               |

Table 7

| NAME | DATE     | HEMOGLOBIN<br>Grams | RBC   | WBC    | DIFFERENTIAL |                |        |       | PLATELETS<br>(Finn's Method) | RETICULO-<br>CYTES<br>(Percent) | RED. RATE<br>Cells<br>(40 minutes) |
|------|----------|---------------------|-------|--------|--------------|----------------|--------|-------|------------------------------|---------------------------------|------------------------------------|
|      |          |                     |       |        | Neutro.      | Squad<br>Forma | Lymph. | Mono. |                              |                                 |                                    |
| A.   | 2/18/53  | 14                  | 4,700 | 11,300 | 51           | -3             | 38     | 3     | 1                            | 3                               | 12                                 |
|      | 3/7/53   | 14.5                |       | 8,300  |              |                |        |       |                              |                                 |                                    |
| B.   | 4/14/53  | 10.8                | 8,160 | 9,000  | 74           | -1             | 21     | 0     | 2                            | 1                               | 1                                  |
|      | 12/13/54 | 10                  |       | 8,300  | 12           |                | 10     | 1     | 3                            | 4                               |                                    |
|      |          |                     |       |        |              |                |        |       | 87,800                       |                                 |                                    |
| B.   | 4/22/53  | 10.5                | 3,800 | 5,000  | 50           | -4             | 35     | 2     | 3                            | 8                               | 9                                  |
|      | 7/23/54  | 13.3                | 3,700 | 6,900  | 45           | -6             | 40     | 5     | 1                            | 1                               | 3                                  |
|      | 11/7/54  | 18.3                |       | 8,300  | 38           |                | 56     | 1     | 5                            | 5                               |                                    |
| B.   | 5/18/53  | 13                  | 4,000 | 9,100  | 53           |                | 34     | 0     | 1                            | 3                               | 19                                 |
| C.   | 10/7/54  | 19                  |       | 10,000 | 82           |                | 35     |       | 2                            | 1.2%                            |                                    |
| K.   | 9/17/53  | 15.5                |       | 6,000  | 70           | 4              | 21     | 0     | 1                            | 1                               |                                    |
| J.   | 3/18/53  | 14.5                | 5,000 | 6,000  | 47           | 7              | 30     | 0     | 3                            | 4                               | 19                                 |
|      | 7/13/54  | 18.7                |       | 8,300  | 45           |                | 43     | 4     | 7                            | 1                               | 23                                 |
| P.   | 9/7/54   | 9.7                 |       | 3,000  | 42           |                | 30     | 1     | 6                            | 2                               | 10                                 |
|      | 9/9/53   | 10                  | 4,100 | 3,300  | 43           | 1              | 30     | 3     | 3                            | 82,000                          |                                    |
| R.   | 5/17/53  | 11                  | 3,400 | 11,200 | 50           | 0              | 29     | 1     | 0                            | 3                               | 21                                 |
|      | 6/17/54  | 11.1                |       | 3,975  | 52           |                | 30     | 0     | 1                            | 2                               | 8                                  |
| R.   | 6/9/53   | 10.3                |       | 8,000  | 43           | 1              | 30     | 3     | 3                            | .45                             | 12                                 |
| O.   | 5/11/53  | 12.0                | 3,300 | 4,600  | 51           | 1              | 45     | 0     | 1                            | 2                               | 6                                  |
|      | 7/13/54  | 12.0                | 4,910 | 6,300  |              |                |        |       |                              |                                 |                                    |
| S.   | 3/13/53  | 11.5                | 4,300 | 7,300  | 64           | 1              | 30     | 1     | 0                            | 4                               | 12                                 |
|      | 11/23/54 | 13                  |       | 6,300  | 62           |                | 31     |       | 4                            |                                 |                                    |
| S.   | 9/53     | 9.9                 |       |        |              |                |        |       |                              |                                 |                                    |
| W.   | 10/24/50 | 13.5                |       | 10,000 | 80           |                | 24     | 1     | 0                            | 7                               | 8                                  |
| W.   | 1/13/53  | 15                  | 5,200 | 6,300  | 41           | 3              | 52     | 1     | 0                            | 2                               |                                    |
|      | 12/9/54  | 16                  |       | 13,000 | 65           |                | 20     | 2     | 1                            |                                 |                                    |

Table 7—Continued

| NAME | DATE     | HEMOGLOBIN<br>Grams | RBC   | WBC    | DIFFERENTIAL |                |        |       | PLATELETS<br>(Finn's Method) | RETICULO-<br>CYTES<br>(Percent) | RED. RATE<br>Cells<br>(40 minutes) |
|------|----------|---------------------|-------|--------|--------------|----------------|--------|-------|------------------------------|---------------------------------|------------------------------------|
|      |          |                     |       |        | Neutro.      | Squad<br>Forma | Lymph. | Mono. |                              |                                 |                                    |
| B.   | 2/2/54   | 11.5                | 4,100 | 6,700  | 63           | 3              | 31     | 1     | 3                            | 1                               | 24                                 |
| C.   | 3/19/54  |                     | 4,000 | 30,000 | 70           |                | 27     |       | 1                            |                                 |                                    |
| D.   | 11/7/53  |                     | 3,710 | 2,400  | 60           |                | 11     |       |                              |                                 |                                    |
| E.   | 2/19/53  | 11.5                | 4,100 | 10,000 | 63           | 3              | 15     | 1     | 0                            | 0                               | 23                                 |
|      | 6/8/54   | 13.5                |       | 6,000  | 60           |                | 21     |       | 2                            | 1                               | 10                                 |
| F.   | 9/7/57   | 6.7                 | 3,400 | 60,000 | 16           |                | 5      |       | 00                           |                                 |                                    |
| G.   | 11/10/53 |                     | 3,300 | 11,200 | 67           |                | 31     | 2     | 0                            | 1                               |                                    |
| H.   | 11/40    |                     |       | 8,000  | 60           |                | 20     |       |                              |                                 |                                    |
|      | 12/40    |                     |       | 8,000  |              |                | 20     |       |                              |                                 |                                    |
|      | 12/53    |                     |       | 4,000  |              |                | 20     |       |                              |                                 |                                    |
| I.   | 1/12/53  |                     | 4,000 | 8,000  | 40           | 3              | 23     | 2     | 0                            | 2                               | 7                                  |
|      | 12/2/54  |                     | 3,800 | 3,700  | 41           |                | 21     | 1     | 2                            | 4                               |                                    |
| J.   | 2/19/53  | 12.0                |       | 3,700  | 67           | 4              | 20     | 0     | 0                            | 1                               | 27                                 |
|      | 7/29/54  | 13.0                | 7,400 | 6,000  | 60           |                | 20     | 0     | 0                            | 2                               | 20                                 |
| K.   | 3/17/53  | 12.0                |       | 9,700  | 63           | 3              | 41     | 0     | 0                            | 0                               | 20                                 |
|      | 7/27/54  | 14.0                |       | 6,000  | 53           | 3              | 43     | 1     | 0                            | 0                               | 10                                 |
| L.   | 6/10/53  | 11.5                | 4,000 | 11,000 | 61           | 3              | 20     | 0     | 0                            | 1                               | 22                                 |
| M.   | 9/20/54  | 14.0                |       | 6,200  | 53           |                | 27     |       | 0                            | 4                               | 9                                  |
|      | 9/20/54  | 15                  |       | 4,000  | 60           |                | 20     |       |                              |                                 | 9                                  |
| N.   | 12/20/51 | 6.0                 |       | 20,000 | 3            | 10             | 4      | 7     | 7                            | .0%                             |                                    |
| O.   | 3/14/55  | 14.0                |       | 5,000  | 50           |                |        |       |                              |                                 |                                    |
| P.   | 9/24/54  | 16.0                |       | 18,000 | 60           |                |        |       |                              |                                 |                                    |

TABLE 8

## THOROTRAST FOLLOW-UP STUDIES

| Year Reported | Total number Patients | Results                                                                                                                                                                                                                                                          | Investigator                                   | Comments                                                                                                                                                       |
|---------------|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1935          | 175                   | No deleterious effects found                                                                                                                                                                                                                                     | Rigler, Koucky and Abraham (93)                | 3.5 year follow-up. 100 patients dead from primary disease. 32 patients unable to trace. 43 patients living and apparently unaffected                          |
| 1942          | 286                   | No deleterious effects found                                                                                                                                                                                                                                     | Iater and Cos (128)                            | 10 year follow-up. 189 patients dead. 67 patients unable to trace. 30 patients examined                                                                        |
| 1951          | 4235                  | Two cases of malignant tumors of liver, and 1 leukemia                                                                                                                                                                                                           | Thomas, Henry and Kaplan (117)                 | Questionnaires sent to 132 radiologists                                                                                                                        |
| 1953          | 235                   | 4 anemias and 2 leukemias                                                                                                                                                                                                                                        | Johansen, Backer, Bundo & Faber (10,30,57,104) |                                                                                                                                                                |
| 1955          | 35                    | 1 hemangio-endothelioma of liver. Induration at site of injection in 4 patients. Minor hematological changes                                                                                                                                                     | Looney, Eareh, Colodzin and Stedman (64,67)    | Retention approximately 15 years. 14 patients dead. Mean age at death 62 years                                                                                 |
| 1956          | 21                    | 1 endothelial cell sarcoma of liver. 1 primary hepatoma of liver. 1 carcinoma maxillary sinus. 9 of 12 patients studied less than 4 million erythrocytes per mm <sup>3</sup>                                                                                     | Fruhling, Gros and Batzen-schlager (36)        | Mean retention approximately 10 years. 12 patients dead                                                                                                        |
| 1958          | 136                   | 3 patients dead from malignant disease other than that for which thorotrast given (i.e. carcinoma of stomach, mouth and lung). None considered to be related to thorotrast. Hematological studies on 26 patients showed only low lymphocyte counts in 2 patients | Berrett and McRae (14)                         | Follow-up of 136 patients who had carotid arteriograms between 1934 and 1950. Evaluation of 134. 66 now dead. None attributable to complications of thorotrast |

FIGURE 1

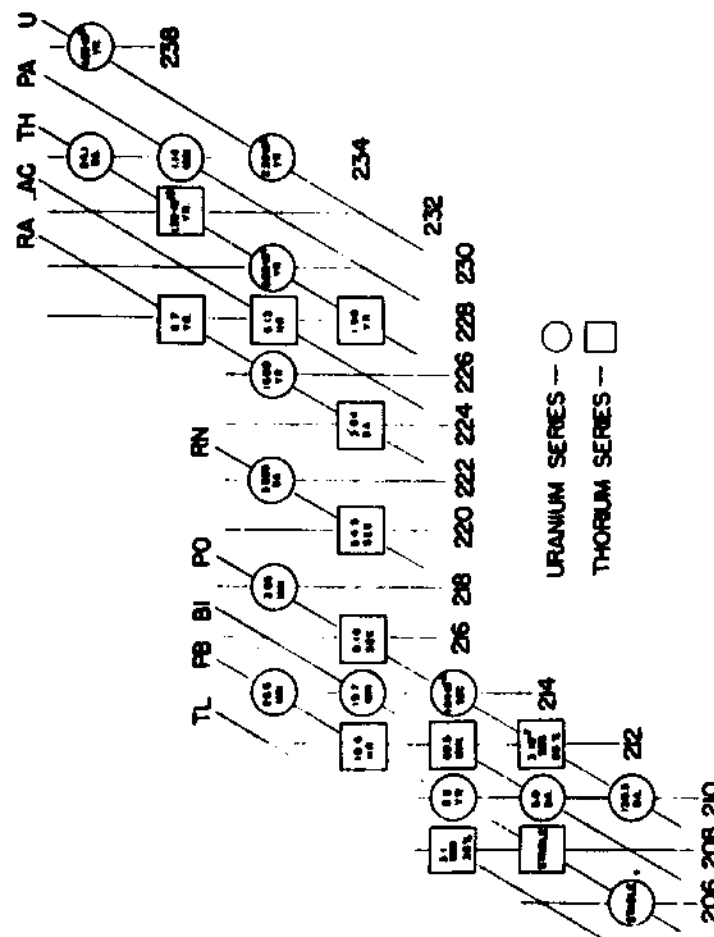


Diagram 1. The decay scheme for the uranium and the thorium series. In general decay progresses from the upper right area to the lower left area of the chart. Progression horizontally to the left occurs when an alpha particle is emitted. Progression downwards connotes a beta particle emission.

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## Mice, Men, and Fallout

The potential danger of strontium-90 is appraised on the basis of data from animal experiments.

Miriam P. Finkel

During the past few years a great deal of effort has been devoted to discovering how much radioactive debris has settled upon the earth and how much more will probably be added as a result of the nuclear weapons already tested and likely to be tested in the future. Even more effort has gone into researches to learn what proportion of this material will become incorporated in living things and how damaging it will be to plants, animals, and man. In addition to these studies, there have been many arm-chair predictions about the numbers of abnormal infants that will be produced each year, the numbers of people who will die of leukemia and bone tumors, and the numbers of years our lives will be shortened because of radioactive contamination. Some of these predictions have been made by well-known and respected scientists, physicians, and statesmen. Consequently, they have gained wide acceptance, and it is generally believed that thousands of individuals throughout the world are doomed because of the present level of radioactive fallout. It is appropriate at this time to examine critically the bases of these predictions and to analyze some of the available data relevant to the problem of the dangers of small amounts of radioactive materials.

It is not my purpose either to condemn future weapon testing or to nod approval to those who wish to try for bigger and better bombs. Problems in the realm of national policy and international relations must be judged by those who have access to the total necessary information, and the laboratory scientist is not likely to be included in this group. However, the laboratory scientist does have a duty to report the facts as he finds them, and there is a growing body of data upon which an evaluation of the potential hazards of radioactive fallout can be based.

It has been established beyond any

possible doubt that irradiation, either from external sources or from radioisotopes within the body, can be dangerous. The manifestations and degree of damage depend upon many factors, such as the type and energy of the rays, the duration of exposure, and the portion of the body involved. In general terms, the major response of the total animal to high levels of irradiation is acute radiation disease and early death. At lower levels, tumor induction and shortening of life are the major signs of damage. In order to assess the dangers of fallout, it is necessary to know what happens at very, very low levels. Such information is completely lacking for man, and it is not easily obtained for experimental animals. Consequently, most predictions have been based upon extrapolations from the effects of higher levels of irradiation. These extrapolations involve two major assumptions. The first is that a linear relationship exists between the size of the dose and the magnitude of the response, so that only a segment of the curve requires experimental verification for accurate projecting of the entire curve. The second assumption is that no dose is so small that it has no effect. Once these premises have been accepted, the task becomes one of collecting all the cases displaying a particular result of irradiation, estimating the doses that produced these cases, and plotting response against dose in such a way that the origin of the extrapolated curve is zero on both scales, as has been done in Fig. 1, curve A. Curve B in Fig. 1 is a variation of curve A with the added complication of "background noise." However, curve C is an equally valid representation of these hypothetical data. Contrary to the other two curves, it assumes that a measurable response does not occur until a certain threshold dose has been exceeded.

The method of thoughtful guessing from a little knowledge is often the only

possible approach to a problem, and the answers it provides are useful as long as they are qualified by the uncertainties of the assumptions that were made. However, the fact that many conclusions concerning the dangers of fallout are based upon incomplete data, partial curves, and speculations of this kind is often ignored.

There are other ways of estimating the human hazards of radioactive contamination. The usefulness of animal experimentation was recognized in the early days of the Manhattan Project (1), and such investigations have been under way since the products of nuclear fission first became available for biological study. Two major approaches have been used. The first takes advantage of the substantial fund of information on radium poisoning in man. It has assumed that the ratio of toxicities of any radioisotope relative to radium should be approximately the same in the experimental animal and in man if appropriate corrections for differences in retention, life span, size, and other factors are applied. The second approach has involved testing the same isotope in different species. The resulting correlations between toxicity and the various species characteristics then serve as a basis for extrapolation to an animal such as man.

Unfortunately, investigations of the long-term effects of small amounts of toxic agents require a great deal of time, the minimum interval for a complete study being the length of life of the longest survivor. Definitive answers from animal experimentation on fission-product toxicity are not yet available, but the data that have been accumulated during the past 14 years provide a reasonably sound basis for a few predictions about the dangers of human contamination with many radioactive materials. Since the greatest interest now centers around strontium-90 fallout from nuclear weapons, the remainder of this article deals with some of the laboratory data on the toxicity of this isotope. These studies (2) are concerned with the effects upon the exposed generation only.

### Experimental Rationale and Methods

The most useful criteria of radiation damage to the mammalian organism as a whole are decrease in life span and increase in the incidence of certain tumors. These changes can be accurately meas-

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ured and evaluated only when large populations are observed during their entire life span. The laboratory mouse is well suited to this type of experimentation because hundreds of animals can be maintained in a relatively small space, and strains with a high degree of genetic and physiologic uniformity can be obtained in large numbers. In addition, since the average mouse lives less than two years, mortality and morbidity data become available within a reasonably short time. However, some of the same characteristics that make the mouse so useful for long-term radiotoxicity studies render direct extrapolation of the data to man impossible. Consequently, information on larger and longer-lived animals is essential to bridge the extreme

differences that exist between mouse and man.

Human contamination with radiostrontium will occur primarily through ingestion, but the effective dose at low levels is expected to be that which becomes incorporated in the skeleton rather than that which passes through the gastrointestinal tract. Therefore, difficulties in the general application of animal data as a result of interspecific differences in absorption characteristics can be minimized by administering the isotope intravenously. Appropriate corrections based upon absorption factors can then be applied when particular exposure situations are being evaluated. Another difference between human contamination from fallout and animal experimentation with intravenous injection is the length of time during which exposure continues. In the former case the body burden is increased gradually; in the latter case the initial amount of strontium 90 in the body may exceed the amount eventually retained in the skeleton by a factor of 10. Prolonged exposure also leads to a more uniform distribution of radiostrontium within the bones. The effects of both the high initial dose rate and the degree of uniformity of deposition are currently being studied in experiments involving several fractionated dose regimens.

Briefly, then, the mouse is providing basic, statistically reliable information on decrease in life span and increase in the incidence of certain tumors after a single, intravenous injection of strontium-90. These data are being supplemented by mouse experiments in which the route and duration of exposure are varied and by experiments on larger, longer-lived animals, such as rats and dogs.

The plan of the strontium-90 toxicity experiment is given in Table I. At high levels only a few animals were used, because the effects were expected to appear rapidly and to be unequivocal; at low levels many animals were required, because the effects were expected to appear late, to be less diagnostic of radiation damage, and to require statistical testing. It was intended that the highest dose should reach or exceed the amount necessary to kill 50 percent of the population in 30 days and that the lowest dose should be so low that the treated animals would be indistinguishable from the controls. The lowest injected dose, 1.3  $\mu\text{C}/\text{kg}$ , resulted in a body burden of approximately 0.14  $\mu\text{C}/\text{kg}$  at 600 days. This is roughly equivalent to 10  $\mu\text{C}$  in a 70-kg man, or to ten times the currently accepted maximum permissible level for personnel engaged in atomic energy

work and to 100 times the level set for the general population (3).

Young adult female mice (strain CF No. 1) were randomized into the permanent experimental groups 1 week before injection. Dose was based upon the average weight of the entire population. Postinjection routine included daily observation of all animals and the sacrifice of moribund mice with Nembutal after a peripheral blood sample had been withdrawn. Autopsy was followed by x-ray examination of the entire skeleton and by histologic study of a number of tissues. All organs with grossly visible lesions and all bones with roentgenographically detected abnormalities were added to the tissues regularly taken for histopathology.

### Results

In Fig. 2 the average survival time has been plotted against dose on a double-logarithmic grid. At dosages of from 1.3 through 68  $\mu\text{C}/\text{kg}$ , the treated animals died, on the average, a little sooner than the control animals, but their deaths were not associated obviously with any particular disease. At dosages of from 200 through 2200  $\mu\text{C}/\text{kg}$ , the primary cause of death was neoplastic disease; at higher dosages it was subcutaneous acute irradiation disease. The values at 1.3, 4.3, and 8.9  $\mu\text{C}/\text{kg}$  are not significantly different from the control value. It was calculated that a difference as small as that noted at the lowest dose would be significant at the 1-percent confidence

Table I. Plan of the strontium-90 toxicity experiment. Female mice, strain CF No. 1, received a single, intravenous injection of an isotonic equilibrium mixture of strontium-90 and yttrium-90 chloride, at pH 5 in 5, when they were approximately 70 days old.

| Group   | No. of animals | Injected dose ( $\mu\text{C}/\text{kg}$ ) | Body burden* ( $\mu\text{C}/\text{kg}$ ) |
|---------|----------------|-------------------------------------------|------------------------------------------|
| 1       | 15             | 9350                                      | 1026                                     |
| 2       | 30             | 7000                                      | 770                                      |
| 3       | 45             | 4500                                      | 495                                      |
| 4       | 30             | 2200                                      | 242                                      |
| 5       | 45             | 880                                       | 97                                       |
| 6       | 45             | 440                                       | 48                                       |
| 7       | 60             | 200                                       | 22                                       |
| 8       | 75             | 88                                        | 9.7                                      |
| 9       | 90             | 44                                        | 4.8                                      |
| 10      | 105            | 8.9                                       | 1.0                                      |
| 11      | 120            | 4.3                                       | 0.5                                      |
| 12      | 150            | 1.3                                       | 0.14                                     |
| Control | 150            | 0                                         | 0                                        |

\* The body-burden figures are based upon 11-percent retention at 600 days after injection (7), which was the average survival time of the control group.

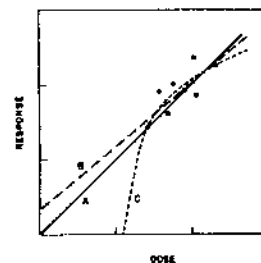


Fig. 1. Possible extrapolations from hypothetical data. (Curve A) This method, the one usually employed, assumes that the origin of the dose-response curve is at zero on both the ordinate and the abscissa. (Curve B) This method also assumes that there is no threshold, but it adds a normal background incidence that prevents an origin at zero on the ordinate. (Curve C) This is an equally acceptable extrapolation from the meager data presented, which assumes that there is a threshold dose that must be exceeded before the response is manifest.

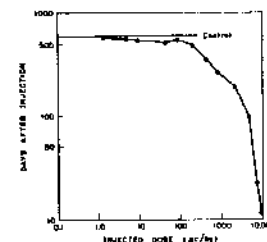


Fig. 2. Average survival time, or life expectancy at the time of injection, plotted as a function of dose.

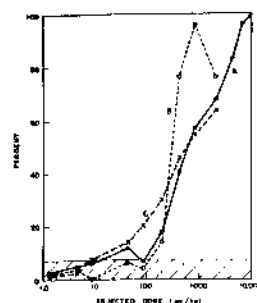


Fig. 3. Effect of strontium-90 on life expectancy and on incidence of tumors of bone and blood-forming tissues. The points within the shaded area are not statistically significantly different from the control values; the shaded area represents nonsignificance at the 10-percent probability level or higher by the *t* test. (Curve A) Percentage decrease in average survival time (life expectancy at start of experiment) compared with average survival time of the controls. (Curve B) Incidence of animals with osteogenic sarcomas among 150-day survivors. The incidence among the control population was 2 percent. (Curve C) Percentage decrease in time to a 20-percent incidence of reticular tissue tumors compared with the 20-percent incidence time of the controls.

level if it had been based upon 1393 treated animals compared with the same number of controls, or almost ten times as many mice as were used to establish these points. This calculation, which is based on the assumption of unchanged variability in a larger population, emphasizes one reason why definitive data at very low levels are difficult to obtain. The lowest injected dose that resulted in a statistically significant decrease in life span was 44  $\mu\text{c/kg}$ . These mice had a retained dose of approximately 3  $\mu\text{c/kg}$ , which corresponds to 350  $\mu\text{c}$  per 70-kg man, or to 350 times the maximum permissible body burden for people engaged in atomic energy work and to 3500 times the level set for the general population.

In Fig. 3, curve A illustrates the percentage decrease in average survival time, compared with the average survival time of the control population, plotted against the logarithm of the dose. Even though the animals that received 44  $\mu\text{c/kg}$  showed a statistically significant decrease in life span, those that received 88  $\mu\text{c/kg}$  did not. This peculiar result was due in part to the fact that the two longest survivors in the entire experiment belonged to this group.

Various tumors that might be attributed to strontium-90 appeared in and around bone. There was a pronounced association between dose and both osteogenic sarcomas and hemangioendotheliomas of bone marrow, and there was a suggested association between dose and epidermoid carcinomas of the oral cavity. Fibrosarcomas adjacent to bone and benign skeletal tumors were not influenced by radiostromium, except insofar as their total incidence was lower at levels that decreased survival time substantially. The proportions of animals that survived the latent period of 150 days and then died with osteogenic sarcomas are shown in Fig. 3, curve B. There were three osteogenic sarcomas among the control mice, an incidence of 2 percent. The lowest injected dose that resulted in a significantly higher number of osteogenic sarcomas was 200  $\mu\text{c/kg}$ . This dose is almost five times larger than the lowest level that resulted in a significant difference in survival. At the next lower dose (88  $\mu\text{c/kg}$ ) there were twice as many tumors as in the control group, but the probability that this was due to chance was 30 to 50 percent, as determined by the *t* test. At 44  $\mu\text{c/kg}$  there were three times as many tumors, with a probability of chance occurrence of 20 to 30 percent.

Other neoplasms occurring in the mouse that are influenced by irradiation are those that show certain similarities to the leukemias of man. This group of tumors has been designated by a variety of names, among which are mouse leukemias, lymphomas, lymphoid tumors, thymic tumors, and reticular tissue tumors. They involve the blood-forming tissues, and they arise primarily in the lymph nodes, thymus, spleen, and bone marrow. Although the total incidence of these tumors was not markedly influenced by dose in this experiment, they appeared much earlier among the animals that had received 88  $\mu\text{c/kg}$  or more. Therefore, the data were examined further for evidence of a relationship between dose and time of death with reticular tissue tumors. In curve C, Fig. 3, the percentage decrease in the number of days from injection to the time when 20 percent of the population had died with tumors of the blood-forming tissues is plotted against the logarithm of the dose. The control animals reached a 20-percent incidence 565 days after the beginning of the experiment. The two lowest points on the curve are not significantly different from the control value; the point at 8.9  $\mu\text{c/kg}$  is significant at the 1-percent confidence level.

This dose is one-fifth of the lowest dose that produced a significant difference in life span. It resulted in a body burden of approximately 1  $\mu\text{c/kg}$ , which is roughly equivalent to 70  $\mu\text{c/man}$ , or to 70 and 700 times the currently accepted maximum permissible levels for occupational and nonoccupational exposure, respectively.

#### Linearity and Threshold

In spite of the many differences that exist between mouse and man, it is most likely that the general laws of radiotoxicity that apply to the mouse also apply to man. The experimental data just presented provide the best current information on the shape and origin of the dose-response curve as measured in the total mammalian organism. Since the greatest interest concerns low amounts of irradiation, the data from only the five lowest dose levels have been replotted in Fig. 4 on a rectangular grid in place of the semilogarithmic grid used in Fig. 3. The latter was necessary in order to include the large range of doses in the complete experiment; the former is required for determinations of linearity.

None of the curves in Fig. 4 can be described by a simple linear function. Although the values of the four lowest dosage groups in curve A (reduction in life span) suggest a direct relationship between dose and response, it is not a linear one. Since three of these values

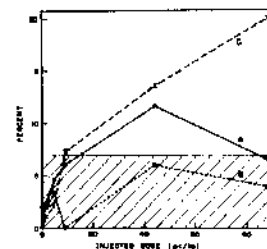


Fig. 4. The relationship of dose and response at low levels. Values above the shaded area are significantly different from the control values. Within the shaded area the probability is 10 percent or greater that there is no difference between the experimental and the control values. (Curve A) Percentage reduction in average survival time. (Curve B) Incidence of animals with osteogenic sarcomas among 150-day survivors. (Curve C) Percentage decrease in time to a 20-percent incidence of reticular tissue tumors.

are not significantly different from the control value, a threshold for the life-shortening effect may lie between 4.5 and 44  $\mu\text{c/kg}$ . However, since the values for 1.3, 4.5, and 8.9  $\mu\text{c/kg}$  do lie along a straight line when plotted semilogarithmically (Fig. 3), it may be argued that they represent true departures from the control value. An extension of this straight line crosses the control value at 0.4  $\mu\text{c/kg}$ .

The incidence of osteogenic sarcomas at these five lowest levels did not extend beyond the statistical limits of the control range, and the data show no trend and no indication of any relationship between dose and response (Fig. 3, curve B). Therefore, a threshold for the induction of these neoplasms in female mice, strain CF No. 1, might lie between 88 and 200  $\mu\text{c/kg}$ . However, since there were two and three times as many tumors among the animals that received 88 and 44  $\mu\text{c/kg}$ , respectively, as there were among the controls, a threshold may actually lie below the latter dose. There were not enough animals at these levels to permit statistical verification of differences as small as those observed.

The three lowest points of the reticular tumor curve that were significantly different from the control value (at 8.9, 44, and 88  $\mu\text{c/kg}$ ) do lie along a straight line (Fig. 4, curve C). The values of the two lowest dose levels (1.3 and 4.5  $\mu\text{c/kg}$ ), which did not differ significantly from the control value, were examined to determine whether they fell within the statistical range of an extension of this straight line. They were found to lie so far beyond this range that there was no serious likelihood that they belonged to it. If these data do not demonstrate that a threshold dose must be exceeded before there is a measurable change in the course of tumors of the blood-forming tissues in CF No. 1 female mice, they at least show that the dose-response curve is not linear.

#### Extrapolation to Man

Since it has not been possible to demonstrate a linear relationship between dose and response, the use of straight-line extrapolations from fragmentary human data may be very misleading. In addition, the evidence that there might be a threshold, and consequently a true maximum "indifference dose" for pathologic change as measured in the total animal, raises serious objection to the practice of extending such lines to an origin at zero response and zero dose.

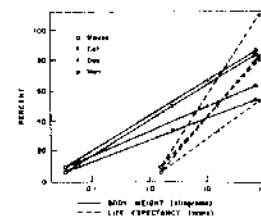


Fig. 5. Estimation of the incidence of osteogenic sarcomas and hemangioendotheliomas of bone marrow in man after an injection of 150  $\mu\text{c}$  of strontium-90 per kilogram. The extrapolations are based upon current data involving mice, rats, and dogs, and they assume a relationship between tumor incidence and body size or life span.

Consequently, other methods of estimating the human hazard from strontium 90 must be used.

**Radium method.** Comparisons of toxicity ratios with radium as the common denominator between experimental animals and man can be applied as follows. The lowest injected doses that increased the incidence of osteogenic sarcomas in CF No. 1 female mice were 44  $\mu\text{c}$  of strontium-90 and 1.2  $\mu\text{c}$  of radium-226 per kilogram (4). This dose of strontium-90 did not significantly increase the incidence of bone tumors related to the controls when evaluated by the *t* test, but since it resulted in the appearance of bone tumors among 6 percent of the treated animals as compared to an incidence of 2 percent among the controls, it was chosen as a probable minimum effective dose. These strontium and radium doses have a ratio of 37 to 1. The largest injected doses tested that did not increase the incidence of osteogenic sarcomas were 8.9  $\mu\text{c}$  of strontium-90 and 0.6  $\mu\text{c}$  of radium-226 per kilogram. This is a ratio of 15 to 1. Thus, at levels in the region of minimum effect, radium is probably somewhere between 15 and 37 times as effective as strontium-90. In a recently reported series of radium-containing human patients, among those

who were probably exposed to relatively pure radium-226 there was one individual with a body burden of 0.4  $\mu\text{c}$  who had minimal but positive roentgenographic evidence of radiation changes (5). There were no positive cases at lower levels among those with body burdens uncontaminated with mesothorium, but most of the patients with from 0.5 to 1.0  $\mu\text{c}$  showed similar, minimal lesions. If 0.4  $\mu\text{c}$  of radium represents a dose of minimum effect in man, applying

the comparative toxicology method. Another approach involves extending the data obtained from a relatively large number of mice, through data obtained from fewer but larger and longer-lived animals, to man. Since the major damage from strontium-90 is due to the energetic beta rays of its yttrium-90 daughter, and since a large proportion of this energy is wasted in an animal as small as a mouse, it is expected that the tumor-producing efficiency of strontium-90 should increase as the size of the animal increases.

The only experiments involving the toxicity of strontium-90 in larger animals that have progressed far enough to be useful for this purpose are two studies including six dogs and six cats that lived more than five months after receiving 150  $\mu\text{c/kg}$  by a single, intravenous injection. Three of the five dogs that have died had osteogenic sarcomas; the sixth is still alive and free of roentgenographic evidence of bone disease. Thus, the first incidence of malignant bone tumors will be 50 or 67 percent. The incidence among mice at the same injected dosage can be estimated to exceed the incidence among the control population by 9 percent. This figure is based upon interpolation between the results obtained at 88 and 200  $\mu\text{c/kg}$  (Fig. 3). When these percentages are plotted against the logarithm of body weight (a 25-g mouse and a 10-kg dog) and extrapolated to a 70-kg man, tumor incidences of 63 and 87 percent are obtained (Fig. 5). When they are plotted against the logarithm of life expectancy (1.6 years for the mouse, 15 years for the dog, and 80 years for man), extrapolation to man gives 80 and 110 percent. These incidences divided by the 9 percent established for the mouse give quotients ranging from 7 to 12. Therefore, strontium-90 might be from 7 to 12 times more effective in man than in mice.

Of the six cats that lived beyond the latent period for tumor induction, two died with osteolytic tumors that have been tentatively diagnosed as hemangioendotheliomas of bone, one died with roentgenographic evidence of the same disease, as yet unverified histologically, and three died free of skeletal malignancies. The incidence of hemangioendotheliomas among mice at 150  $\mu\text{c/kg}$  would be expected to exceed the inci-

dence among the control population by 6 percent on the basis of the incidences at 88 and 200  $\mu\text{C}/\text{kg}$  (6). The projected incidences for man based upon cats weighing 2.5 kg and having a life expectancy of 15 years range from 54 to 84 percent (Fig. 5). These incidences divided by the 6 percent established for the mouse give quotients of from 9 to 14.

These extrapolations from mice through dogs and cats suggest that strontium-90 is from 7 to 14 times as toxic in man as in mice. The lowest dose that could be shown to have any effect in the mouse was 8.9  $\mu\text{C}/\text{kg}$ , which decreased the time interval to the appearance of reticular tissue tumors. This is equivalent to 1  $\mu\text{C}$  retained per kilogram, or to a body burden of 70  $\mu\text{C}$  per 70-kg man. Dividing this dose by the mouse to man factor of from 7 to 14 leads to the estimate that the minimum effective dose in man may be a body burden of from 5 to 10  $\mu\text{C}$  of strontium-90.

#### Danger from Present Fallout Contamination

Perhaps it is merely coincidence that the 8 to 15  $\mu\text{C}$  estimated for the minimum effective dose in man based on the ra-

dium method of extrapolation and the 5 to 10  $\mu\text{C}$  estimated from the mouse, dog, and cat data are so similar. In spite of their very tentative nature, these calculations are presented here to illustrate how experimental animal data may be used. In the next few years there should be additional information on radium toxicity in man, since several hundred persons with a possible radium burden are currently under investigation. Consequently, the level of minimum effect will be known with greater exactness. Also, the dog experiments now in progress in several laboratories should provide information over a range of doses so that extrapolations from mouse through dog to man will be possible at more than one level.

The lowest prediction of a harmful dose to man that can be made from the present data attaches significance to the statistically insignificant differences in average survival time at the lowest doses in the mouse experiment. The line passing through these points intersects the control value at an injected dose of 0.4  $\mu\text{C}/\text{kg}$ . This dose is equivalent to a retained dose in mice at 600 days of 0.044  $\mu\text{C}/\text{kg}$ , or to a body burden in a 70-kg man of 3.08  $\mu\text{C}$ . If the life-shortening factor in going from mouse to man

is as great as the estimated tumor-inducing factor—an unlikely assumption for several reasons—a threshold value for man would lie between 0.22 and 0.44  $\mu\text{C}$  of strontium-90. A more likely value is one that lies between 5 and 15  $\mu\text{C}$ , as discussed above. In any case, the present contamination with strontium-90 from fallout is so very much lower than any of these levels that it is extremely unlikely to induce even one bone tumor or one case of leukemia.

#### References and Notes

1. The Manhattan Project, which developed the atomic bomb, was terminated in 1947. The biological work in progress at that time was continued without interruption under the sponsorship of the newly created Atomic Energy Commission.
2. This work was performed under the auspices of the U.S. Atomic Energy Commission. The views expressed are my own and do not necessarily reflect those of the Biological and Medical Research Division of Argonne National Laboratory.
3. *Natl. Bur. Standards (U.S.) Handbook No. 37* (U.S. Dept. Commerce, Washington, D.C., 1955).
4. M. F. Finkel, *Proc. Soc. Exptl. Biol. Med.* 85, 494 (1955).
5. W. B. Lousner, R. J. Harnett, A. M. Brown, E. Skirant, *Am. J. Roentgenol. Radiat. Therapy* 73, 1006 (1955).
6. M. F. Finkel, B. O. Biskin, O. M. Scribner, *Argonne Natl. Lab. Biol. and Med. Research Div. Semian. Rept. No. ANL-5841*, in press.
7. M. F. Finkel, B. J. Tellebach, J. Levine, B. O. Biskin, *Argonne Natl. Lab. Biol. and Med. Research Div. Semian. Rept. No. ANL-5732* (1957), p. 21.

#### EXTRACT FROM "PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES" JANUARY 1959

#### THE EFFECTS OF STRONTIUM-90 ON MICE\*

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Communicated November 17, 1958

On Sept. 19, 1958 there was published in *Science* a paper by Dr. Miriam P. Finkel of Argonne National Laboratory in which she communicated her observations on the effects of strontium-90 injected into mice on life expectancy and on incidence of tumors of bone and blood-forming tissues.<sup>1</sup> She discussed the question of whether or not the effects are proportional to the amount of injected strontium-90 at low doses, and reached the conclusion that it is likely that there is a threshold with value for man between 5 and 15  $\mu\text{C}$ . (as compared with the present average value from fallout, about 0.0002  $\mu\text{C}$ ., and the predicted steady-state value from fallout for testing of nuclear weapons at the average rate for the past five years, about 0.02  $\mu\text{C}$ .). Her paper ends with the sentence "In any case, the present contamination with strontium-90 from fallout is so very much lower than any of these levels that it is extremely unlikely to induce even one bone tumor or one case of leukemia."

On the same day, Sept. 19, 1958, newspapers throughout the United States published accounts of this work. For example, the Pasadena (Calif.) *Star-News* contained an article with the headline "Tests on Mice Show Fallout Safe" and the first sentence, "A woman researcher says tests on mice show that the present fallout from nuclear weapons tests will not produce a single case of bone cancer or leukemia in humans." The *New York Times* published accounts of the work on both September 19 and September 28.

We have made an analysis of Dr. Finkel's data that shows that she had no justi-

fication whatever for her concluding statement. All of her data are compatible with a zero threshold for strontium-90. Moreover, the statistical analysis shows that in order for Dr. Finkel to have been justified with 90 per cent confidence (10 per cent type-II error) in making her concluding statement on the basis of her data she would have to have used over 1,000,000,000,000 mice in each of her groups, instead of the 150 or less that were used. It is hard for us to understand how such a serious error could be made in Dr. Finkel's argument, leading her to publish her seriously misleading statement about this matter of great importance.

*The Mice Experiments.* In the studies described by Dr. Finkel young adult female mice (strain CF No. 1, about 70 days old) were given a single intravenous injection of an isotonic equilibrium mixture of strontium-90 chloride and yttrium-90 chloride. There were twelve injected groups, ranging in size from 150 mice for the group receiving the smallest amount (1.3  $\mu\text{c/kg}$  body weight) to 15 for that receiving the largest amount (9330  $\mu\text{c/kg}$ , an amount that caused death of about 50 per cent within 30 days). The control group contained 150 mice. The author states that there is 11 per cent retention (at 600 days) of the injected radioactive material. Report was made of the fractional decrease in average survival time, the incidence of animals with osteogenic sarcomas (among 150-day survivors), and the fractional decrease in time to a 20 per cent incidence of reticular tissue tumors compared with the 20 per cent incidence time of the controls.

Studies of this sort may be of great value in providing information about the probable amount of damage done to human beings by exposure to high-energy radiation, such as that from strontium-90 produced by nuclear weapons. It is important that the analysis of the experimental results be carried out correctly. We have found that in the treatment of problems of this sort the assumption that the probability of damage is strictly proportional to the amount of radiation exposure does not in general require that a response such as decrease in life expectancy be linear, except over a very small range. Moreover, we have found that this assumption together with the theory of statistics can be applied in a reasonably straightforward way in the discussion of data such as those obtained by Dr. Finkel, as shown in the following sections.

*Analysis of the Experimental Data on Life Shortening.*—Our analysis proceeds from the hypothesis, induced by Lewis<sup>2</sup> as a result of his study of the incidence of leukemia, that exposure of the bone marrow of an animal to radiation results in an increase in the probability per unit time that the animal will die at any time thereafter, the increase being proportional to the quantity of radiation absorbed. We shall suppose that this hypothesis applies to all of the radiation-induced effects in Dr. Finkel's experiments with mice.

Let  $N_0$  be the number of animals at the beginning of a given experiment, taken to be at  $t = 0$ , and let  $N(t)$  be the expected number (average for many experiments of the same kind) at the later time  $t$ . Further, let  $N^0(t)$  be the expected number in a "control" experiment in which no strontium-90 is injected, so that

$$g(t) \equiv -\frac{1}{N_0} \frac{dN^0}{dt}$$

is the natural specific death-rate function. We denote by  $\alpha$  the quantity of strontium-90, in  $\mu\text{c/kg}$  body weight, that is retained in the animals. Then our hypothesis yields the equation

$$\frac{dN}{dt} = -N\beta\alpha t - \frac{N}{N^0(t)} \cdot N_0 g(t) \quad (1)$$

where  $\beta$  is a constant of proportionality relating the quantity of strontium-90 retained to the increased probability per unit time that the animals will die, this probability of course increasing linearly with time owing to the nearly constant irradiation by the decaying strontium-90.

Let  $n^0(t) = N^0(t)/N_0$ , so that  $g(t) = -\dot{n}^0(t)$ . Then on integrating equation (1) we obtain

$$\begin{aligned} N &= N_0 \exp \left[ -\frac{1}{2} \beta \alpha t^2 - \int_0^t \frac{\dot{n}^0(t)}{n^0(t)} dt \right] \\ &= N_0 n^0(t) e^{-(1/2)\beta \alpha t^2} = N^0(t) e^{-(1/2)\beta \alpha t^2} \end{aligned} \quad (2)$$

To compare this result with the experimental data we calculate  $\Delta$ , the fractional decrease in life expectancy (fractional decrease in average survival time after injection),

$$\Delta = \frac{t_0 - t_a}{t_0}$$

where  $t_a$  is the life expectancy for a retained quantity  $\alpha$  of strontium-90,

$$t_a = \frac{1}{N_0} \int_0^\infty N(t) dt \quad (3)$$

The equation for  $\Delta$  is

$$\Delta = 1 - \frac{1}{t_0} \int_0^\infty n^0(t) e^{-\gamma t^2} dt \quad (4a)$$

$$= \frac{1}{t_0} \int_0^\infty \left( t - \frac{1}{2} \sqrt{\frac{\pi}{\gamma}} \operatorname{Erf} t \sqrt{\gamma} \right) g(t) dt \quad (4b)$$

where for simplicity we put  $\gamma = \frac{1}{2} \alpha \beta$ . The result in equation (4b) is obtained by an integration by parts, and the error function is defined as

$$\operatorname{Erf} x = \frac{2}{\sqrt{\pi}} \int_0^x e^{-y^2} dy$$

If normally (for  $\alpha = 0$ ) all animals lived to the age  $t_0$  and then died, so that  $g(t)$  were a delta function  $\delta(t - t_0)$ , then we would have simply

$$\Delta = 1 - \frac{\sqrt{\pi}}{2} \frac{\operatorname{Erf} t_0 \sqrt{\gamma}}{t_0 \sqrt{\gamma}} \quad (5)$$

However, the actual lifetimes scatter with sizable dispersion about  $t_0$ . The extent of this dispersion can be estimated from the acceptance region  $\Delta \leq 0.07$  quoted by Dr. Finkel (Figs. 3 and 4) as appropriate to a test of the hypothesis of no difference between the responses of the control population and of a population injected with a given dose of strontium-90. If we assume (1) that the test of no difference applies to Curve A, the life-shortening data, (2) that the test was one-tailed, and (3) that the test accounted for the uncertainty in the mean lifetime of the control population and for the uncertainty in the mean lifetime of her group 10, the highest-dosed population to fall within the acceptance region (except for the "peculiar result" for group 8), then we find that the estimated standard deviation for  $g(t)$  is  $\hat{\sigma} = 258$  days.

These assumptions are somewhat uncertain, as explained later, but they are the best that can be made from the information given in Dr. Finkel's paper. The uncertainty in drawing any conclusions about  $g(t)$  from Dr. Finkel's data lead us to take a more general approach. Gompertz discovered that for animal populations the logarithm of the "age-specific death rate" is closely a linearly increasing function of time. For man the age-specific death-rate doubling time is about 8 years. Jones<sup>3</sup> has pointed out that the doubling times for different animal species are approximately proportional to the mean life spans for the species. We shall use this information to derive a hypothetical death-rate function  $g(t)$  for the mouse population used in Dr. Finkel's experiments.

The Gompertz law is

$$\ln g(t) = C + Bt \quad (6)$$

which yields

$$n^0(t) = \exp [-A(e^{Bt} - 1)] \quad (7)$$

where  $A (= e^C/B)$  is a constant and where  $B$  is related to the doubling time  $\tau_D$  by

$$B = \frac{\ln 2}{\tau_D} \quad (8)$$

$A$  is to be chosen so as to give the correct mean life span:

$$t_0 = \int_0^\infty \exp [-A(e^{Bt} - 1)] dt = \frac{e^A}{B} [-\text{Ei}(-A)] \quad (9)$$

The exponential integral  $\text{Ei}(x)$  is defined by Jahnke and Emde.<sup>4</sup> If  $t = 0$  is taken to be a time shortly after birth, but long enough after birth to exclude infant deaths (which are omitted in Gompertz' treatment), then  $t_0$  is  $T$ , the mean life span from birth to death. If then  $T/\tau_D$  is a constant for all animal species, we find from equations (8) and (9) that  $A$  is a constant, independent of species, given by the solution of the equation

$$e^A [-\text{Ei}(-A)] = \frac{T}{\tau_D} \ln 2 \quad (10)$$

Assuming  $T = 60$  years for man, with  $\tau_D = 8$  years, we find  $A = 0.0032$ . The solution of equation (9) is obtained with the help of the expansion<sup>4</sup>

$$-\text{Ei}(-x) = -\ln x + x - \frac{x^2}{2!} + \dots \quad (11)$$

where  $\Gamma = 1.781$ .

The death-rate function is

$$g(t) = AB \exp [Bt - A(e^{Bt} - 1)]$$

The dispersion of life spans is measured by the standard deviation  $\sigma$  of  $g(t)$ :

$$\sigma^2 = \int_0^\infty t^2 g(t) dt - t_0^2 = 2 \int_0^\infty t \ln^2(t) dt - t_0^2$$

The second expression results from an integration by parts. A numerical integration is required to obtain  $\sigma^2$ , which can most easily be carried out with  $n^0(t)$  values from equation (7). In this way we find from equations (9) and (10), with  $t_0 = T$ , that

$$\sigma = 0.24T$$

For Dr. Finkel's mice, reported to have  $T = 670$  days, we have  $\sigma = 161$  days, in rather poor agreement with the value  $\sigma = 258$  days inferred above from her paper.

In the calculations that follow we have used equations (7) and (10), with the assumption  $T = t_0 = 600$  days, although actually the mice were about 70 days old at the beginning of the experiment. Thus we have used a doubling time  $\tau_D$  of 80 days, and our  $g(t)$  has standard deviation  $\sigma = 141$  days. The assumption  $\tau_D = 80$  days agrees with the value quoted by Jones<sup>3</sup> for mice. Values of  $n^0(t)$  for these parameters are given in Table 1. The difference between assuming  $T = 600$  days and assuming  $T = 670$  days is not great; in fact, survival curves calculated from equation (5), which assumes  $\sigma = 0$ , do not differ greatly from curves obtained by the more refined procedure that we have used.

TABLE 1

| $t$<br>(Days) | $n^0(t)$ | $n - \mu t^2$ |
|---------------|----------|---------------|
| 0             | 1.000    | 1.000         |
| 80            | 0.997    | 0.997         |
| 160           | 0.990    | 0.987         |
| 240           | 0.978    | 0.972         |
| 320           | 0.953    | 0.950         |
| 400           | 0.908    | 0.923         |
| 480           | 0.818    | 0.891         |
| 560           | 0.666    | ...           |
| 640           | 0.443    | ...           |
| 720           | 0.195    | ...           |
| 800           | 0.038    | ...           |
| 880           | 0.000    | ...           |

We proceed now to compare equation (4a), evaluated with the help of equations (7) and (10), with the experimental life-shortening data. We assume with Dr. Finkel that  $\alpha = 0.11\alpha^*$  where  $\alpha^*$  is the injected dose of strontium-90 in  $\mu\text{C/kg}$  body weight, and we attempt to choose the available parameters so as best to reproduce the observed life-shortening data  $\Delta(\alpha^*)$ . There are two parameters: the constant  $\beta$ , and the no-dose life-shortening  $\Delta_0$ , the latter arising from the fact that we cannot give great weight to Dr. Finkel's zero point because of the statistical uncertainty

in the observed mean life span of the control population. Thus the theoretical curve to be fitted to the data is

$$\Delta(\alpha^*) = \Delta_0 + 1 - \frac{1}{t_0} \int_0^\infty n^0(t) e^{-(0.11/2)\beta\alpha^*t} dt \quad (12)$$

The inclusion of  $\Delta_0$  simply as a constant in equation (12) is not strictly correct: the additive term arising from an adjustment of the zero point should be written  $\Delta_0(\alpha^*)$ , where  $\Delta_0(\alpha^*)$  is a somewhat complicated decreasing function of  $\alpha^*$  that tends to zero as  $\alpha^* \rightarrow \infty$ . For simplicity, however, we ignore this complication, which proves to be unimportant for the lower radiation levels ( $\alpha^* \leq 1000 \mu\text{c/kg}$ ), and which in any case does not much change the results obtained, because  $\Delta_0$  is small.

For very small values of  $\alpha^*$  equation (12) reduces to

$$\begin{aligned} \Delta(\alpha^*) &= \Delta_0 + \alpha^* \left[ \frac{1}{2} (0.11)\beta \int_0^\infty n^0(t) t^2 dt \right] \\ &= \Delta_0 + \alpha^* \left. \frac{d\Delta}{d\alpha^*} \right|_{\alpha^*=0} \end{aligned} \quad (13)$$

This is the linear response region. We can therefore choose preliminary values of  $\Delta_0$  and  $\beta$  by estimating a linear fit to the experimental points at low values of  $\alpha^*$ . The integration in equation (13) is performed numerically, with use of equation (7).

We have calculated theoretical curves from equation (12) in three steps: (1) For  $\alpha^* \leq 50 \mu\text{c/kg}$  equation (13) applies; (2) for selected values of  $\alpha^*$  in the range  $50 \leq \alpha^* \leq 1000$  we carry out the integration in equation (12) numerically, using time intervals  $\Delta t = 80$  days; (3) for  $\alpha^* > 1000$  it is found that the asymptotic form of equation (12) is valid:

$$\Delta(\alpha^*) = \Delta_0 + 1 - \frac{1}{t_0} \sqrt{\frac{\pi}{0.11\beta\alpha^*}} \quad (14)$$

Because we wish to examine the result statistically, we adjust the parameters by a weighted least squares procedure. We calculate two theoretical curves  $y = f_0 + f(x, \beta_1)$  and  $y = f_0 + f(x, \beta_2)$  (here  $y$  is fractional life shortening,  $\Delta$ ;  $x$  is injected dose,  $\alpha^*$ ; and  $f_0$  is the constant  $\Delta_0$ ) for two nearly correct values  $\beta_1$  and  $\beta_2$  of the parameter  $\beta$ . We ask for values  $\hat{f}_0 = f_0 + \Delta f_0$  and  $\hat{\beta} = \beta_1 + (\beta_2 - \beta_1)\delta$  of the parameters such that the weighted sum of the squares of the differences between the experimental values  $y_i$  and the theoretical values  $y(x_i)$  is a minimum:

$$\sum_i w_i (y_i - f(x_i, \hat{\beta}) - \hat{f}_0)^2 = \min \quad (15)$$

Since  $\beta_2 - \beta_1$  is small we can assume that

$$\begin{aligned} f(x_i, \hat{\beta}) &= f(x_i, \beta_1) + [f(x_i, \beta_2) - f(x_i, \beta_1)]\delta \\ &= f(x_i, \beta_1) + \Delta f \delta \end{aligned} \quad (16)$$

The parameter adjustments  $\Delta f_0$  and  $\delta$  are then given by

$$\begin{aligned} \Delta f_0 &= \frac{(\sum w_i \Delta y_i) (\sum w_i \Delta f_i^2) - (\sum w_i \Delta y_i \Delta f_i) (\sum w_i \Delta f_i)}{(\sum w_i) (\sum w_i \Delta f_i^2) - (\sum w_i \Delta f_i)^2} \\ \delta &= \frac{(\sum w_i \Delta y_i \Delta f_i) (\sum w_i) - (\sum w_i \Delta y_i) (\sum w_i \Delta f_i)}{(\sum w_i) (\sum w_i \Delta f_i^2) - (\sum w_i \Delta f_i)^2} \end{aligned} \quad (17)$$

where  $\Delta y_i = y_i - f_0 - f(x_i, \beta_1)$ .

The weights  $w_i$  appearing in equations (15) and (17) should be inversely proportional to the *a priori* variances of the experimental values  $y_i$ . We take the variances to be inversely proportional to the number of animals in each experimental group. This ignores the effect of radiation in changing the dispersion of life spans, but a detailed examination shows it to be a not unreasonable procedure.

The theoretical curve obtained in the above manner is shown in Figure 1, with

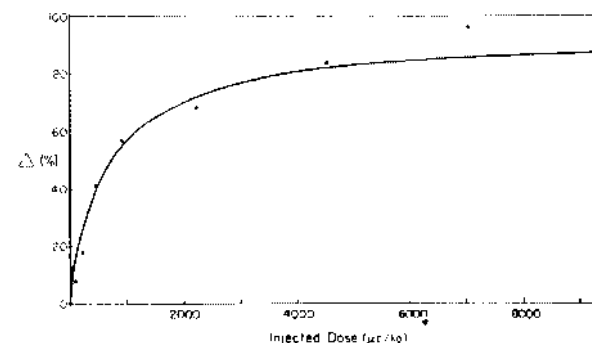


Fig. 1.—Percentage decrease in life expectancy,  $\Delta$ , as a function of injected dose  $\alpha^*$  of strontium-90. Solid curve is the theoretical curve calculated from equation (12). Solid circles are the experimental values reported by Dr. Finkel.

the experimental points for comparison. The two points at highest radiation levels lie well above the curve, doubtless because the mechanism of life shortening at the high radiation levels departs from what we have assumed, owing to the importance of subacute and acute irradiation disease, which Dr. Finkel reports to be the primary cause of death at injected doses above  $2200 \mu\text{c/kg}$ . These points make little contribution to the least squares parameter adjustment, owing to their low weights, and can be omitted without sensibly changing the result. The parameters obtained are  $\beta = 1.8 \times 10^{-7} \text{ day}^{-1} (\mu\text{c/kg retained})^{-1}$ , and  $\Delta_0 = 2.5$  per cent.

The least-squares-fitted curve can be used to estimate the death-rate standard deviation  $\sigma$ : for experimental  $\Delta$  values of unit weight (taken here to be for the control group and "group 12"), the estimated variance of the experimental  $\Delta$  values is

$$\sigma^2 = \frac{1}{m-2} \sum_{i=1}^m w_i [y_i - \hat{f}_0 - f(x_i, \hat{\beta})]^2 \quad (18)$$

where  $m$  is the number of experimental points. Equation (18) takes into account the two-parameter adjustment. If  $M$  is the number of animals in groups having unit weight, then

$$\hat{\sigma}^2 = M \hat{\sigma}_A^2 \quad (19)$$

From equations (18) and (19) we find  $\hat{\sigma} = 191$  days in case the two highest points mentioned above are omitted ( $\hat{\sigma} = 222$  days in case they are included). Comparing the value 191 days with the value  $\sigma = 161$  days based on the Gompertz death-rate curve (670-day life span) and the value  $\hat{\sigma} = 258$  days inferred from Dr. Finkel's data, we see that the theoretical curve fits the experimental values about as well as would be expected from the Gompertz curve, and somewhat better than would have been expected on the basis of Dr. Finkel's acceptance region.

In Figure 2 there is shown the portion of the theoretical curve for the lower radi-

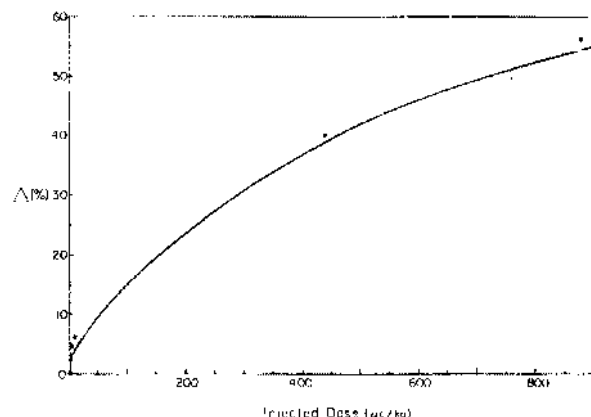


Fig. 2.—Percentage decrease in life expectancy in the low-dose region of Dr. Finkel's experiments. Theoretical curve and experimental points as in Fig. 1.

ation levels. The curvature is pronounced, and the linear response region is restricted to injected doses less than about 50  $\mu\text{c/kg}$ . Most of Dr. Finkel's experiments were carried out in the nonlinear portion of the curve.

It is interesting to compare the above analysis with an alternative one based on the approach developed by Jones,<sup>2</sup> in which the effect of a given exposure of an animal to radiation is regarded as equivalent to an increase in physiological age of the animal by an amount proportional to the amount of radiation received. In terms of the Gompertz formulation of the natural death rate, this results in the case we are considering to the addition of a linear term in  $t$  to equation (6):

$$\ln \left( -\frac{1}{N} \frac{dN}{dt} \right) = C + Bt + B\eta\alpha t \quad (20)$$

The constant  $B\eta$  in this treatment plays a role analogous to the constant  $\beta$  used previously.

From equations (3) and (20) we obtain

$$t_\alpha = \frac{-\text{Ei} \left( -\frac{A}{1 + \eta\alpha} \right)}{B(1 + \eta\alpha)} e^{A/(1 + \eta\alpha)} \quad (21)$$

where  $A = e^C/B$  as before. In practice  $A$  is so small that the exponential integral can adequately be approximated by the logarithmic term in equation (11):

$$-\text{Ei} \left( -\frac{A}{1 + \eta\alpha} \right) = \ln \frac{1}{\Gamma A} + \ln(1 + \eta\alpha) \quad (22)$$

Recognizing from equations (21) and (22) that

$$t_0 = \frac{1}{B} \ln \frac{1}{\Gamma A}$$

and making use of equation (8), we obtain

$$\Delta = 1 - \frac{1 + \epsilon \ln(1 + \eta\alpha)}{1 + \eta\alpha} \quad (23)$$

where  $\epsilon = \tau_{10}/(t_0 \ln 2) \cong 1/5$ .

By choosing  $\eta = 0.014$  ( $\mu\text{c/kg}$  retained)<sup>-1</sup>, and by adjusting the zero point slightly as done previously, we calculate from equation (23) a theoretical curve that matches closely the curve calculated from equation (12), which is the curve shown in Figures 1 and 2. The discrepancy in  $\Delta$  between the two curves is less than 0.02 over the range  $0 \leq \alpha^* \leq 3000$   $\mu\text{c/kg}$ , and increases to 0.04 at  $\alpha^* = 9000$   $\mu\text{c/kg}$ . The two curves fit the experimental data equally well, as shown by the estimates  $\sigma = 191$  days for the curve from equation (12) and  $\sigma = 189$  days for equation (23), calculated by the weighted sum-of-squares procedure described previously. Life-shortening data, at least of the accuracy involved here, are therefore unable to discriminate between the two analytical approaches.

**Analysis of Incidence of Leukemia and Related Diseases.**—The experimental data on the incidence of diseases of the blood and blood-forming tissues can be analyzed in the framework of the above treatment. However, because of the peculiar form in which the experimental results are presented ("Curve C: percentage decrease in time to a 20 per cent incidence of reticular tissue tumors compared with the 20 per cent incidence time of the controls"), the analysis is subject to greater uncertainties and difficulties and the data cannot so readily be evaluated statistically as those for the decreased life expectancy. We therefore content ourselves with a somewhat sketchy treatment, which should suffice to indicate the general nature of the problem.

Let  $\lambda(t, \alpha)$  be the expected number of deaths due to these diseases that have occurred by the time  $t$  in a population having retained body burden  $\alpha$  of strontium-90. We may then expect to find a death-rate probability parameter  $\beta_i$  for these diseases such that the death rate is

$$\frac{d\lambda}{dt} = N(t)\beta_i\alpha t + \frac{d\lambda_0}{dt} \frac{N(t)}{N^0(t)}$$

where  $\lambda_0(t)$  is the number of deaths due to these diseases expected in the control population. To carry the analysis further we need to know the function  $\lambda_0(t)$ , but unfortunately Dr. Finkel presents no data that enable us to determine it. Of the various assumptions that could be made, we have chosen to assume that the nat-



ural deaths due to leukemia are distributed as though they were radiation-induced according to the same model as the deaths due to radiation from strontium-90. The natural leukemia death rate will then be equivalent to a "background" body burden  $\alpha_0$  of strontium-90, and equation (20) becomes

$$\frac{d\lambda}{dt} = N(t)\beta_i(\alpha_0 + \alpha)t$$

Obtaining  $N(t)$  from equation (2), we have

$$\frac{\lambda(t)}{N_0} = \beta_i(\alpha_0 + \alpha) \int_0^t n^0(t) e^{-(1/2)\beta_i \alpha_0 t} dt$$

The expected 20 per cent incidence time  $\tau$  is then the implicit solution of

$$0.11\beta_i(\alpha_0^* + \alpha^*) \int_0^\tau n^0(t) e^{-(0.11/2)\beta_i \alpha^* t} dt = \frac{1}{5} \quad (24)$$

and the expected no-dose 20 per cent incidence time  $\tau_0$  is given by

$$0.11\beta_i \alpha_0^* \int_0^{\tau_0} n^0(t) dt = \frac{1}{5} \quad (25)$$

$\tau_0$  as given by equation (25) is not necessarily the same as the 20 per cent incidence time  $\tau_0' = 565$  days observed for the control population.

To compare the theory with the experimental data we calculate from equation (24) the fractional decrease function  $1 - \tau(\alpha^*)/\tau_0'$ . An adequate approximate calculation for values of  $\tau$  less than about 450 days ( $1 - \tau/\tau_0' > 0.20$ ) can be made by approximating  $n^0(t)$  by a Gaussian  $e^{-\mu^2 t}$ , as shown in Table 1. In this case equation (24) becomes

$$0.11\beta_i(\alpha_0^* + \alpha^*) = \frac{\mu + \frac{1}{2}(0.11)\beta_i \alpha^*}{5 \left[ 1 - \exp \left( -\tau^2 \left( \mu + \frac{1}{2} 0.11\beta_i \alpha^* \right) \right) \right]} \quad (26)$$

To evaluate the parameters  $\beta_i$  and  $\alpha_0^*$  we have fitted a smooth curve, by eye, to the experimental values of  $1 - \tau/\tau_0'$ , and used this curve to pick pairs of values ( $\alpha^*$ ,  $\tau(\alpha^*)$ ) from which the quantity  $0.11\beta_i(\alpha_0^* + \alpha^*)$  was calculated from equation (26). The quantity  $0.11\beta_i \alpha_0^*$  was calculated from equation (25) by numerical integration, with the assumption  $\tau_0 = \tau_0'$ . When plotted against  $\alpha^*$ , the values of  $0.11\beta_i(\alpha_0^* + \alpha^*)$  calculated in this way lie nicely along a straight line, as required by the theory, for values of  $\alpha^*$  in the range  $0 \leq \alpha^* \leq 1000 \mu\text{c/kg}$ . Above  $1000 \mu\text{c/kg}$  the linear relation breaks down, reflecting the fact that the one experimental value in this higher range, at  $2200 \mu\text{c/kg}$ , lies rather far from the theoretical curve. Ignoring this highest value we obtain in this way the parameters  $\beta_i = 0.7 \times 10^{-7} \text{ day}^{-2} (\mu\text{c/kg})^{-1}$  and  $\alpha_0^* = 200 \mu\text{c/kg}$ , from which the theoretical curve shown in Figure 3 is calculated. In addition to the point  $\tau(0)$ , and the points  $\tau(\alpha^*)$  calculated from equation (24) over the range of validity of the Gaussian approximation, we have calculated the slope of the theoretical curve at  $\alpha^* = 0$  from the following formula, which can be derived from equation (24):

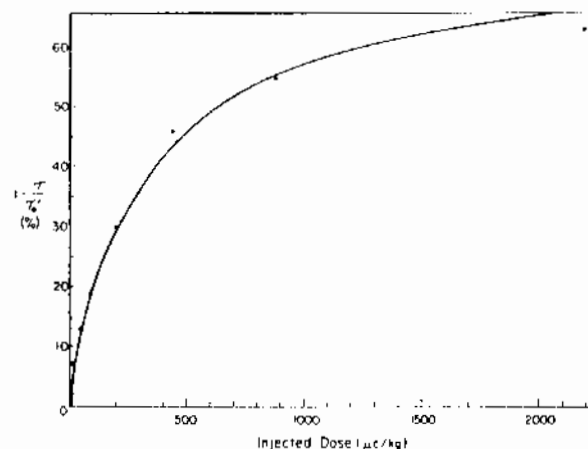


Fig. 3.—Percentage decrease in time to a 20 per cent incidence of bone tumors, as a function of injected dose of strontium-90. Solid curve is calculated from equation (26). Solid circles are experimental values reported by Dr. Finkel.

$$\frac{d}{d\alpha^*} \left( 1 - \frac{\tau}{\tau_0} \right)_{\alpha^*=0} = \frac{1 - \frac{\beta}{10\beta_i} \frac{\int_0^{\tau_0} n^0(t) dt}{\left[ \int_0^{\tau_0} n^0(t) dt \right]^2}}{10\gamma_0^2 \tau_0^2 n^0(\tau_0)} \cdot \frac{1}{2} (0.11)\beta_i$$

where  $\gamma_0 = 1/2(0.11)\beta_i \alpha_0^*$ . The ratio of integrals appearing in the second term of the numerator in this equation can be shown to have a value close to unity (actually 1.06).

A comparison of the parameters  $\beta_i = 0.7 \times 10^{-7}$  and  $\beta = 1.8 \times 10^{-7}$  suggests that of the radiation-induced deaths the fraction due to leukemia and related diseases in Dr. Finkel's experiments on mice is rather larger than has been estimated for man. A particular sensitivity to these diseases on the part of this strain of mice is suggested also by the large "background dose level"  $\alpha_0^*$ , reflecting the relatively large number of deaths due to these diseases in the control population.

**Statistical Examination of Dr. Finkel's Conclusions.**—In searching for evidence for the existence of a threshold body burden of strontium-90, below which no harmful effects are caused, Dr. Finkel uses two methods: (1) statistical analysis of the experimental data, and (2) extrapolation of experimental curves. We now consider these two methods.

The statistical analysis consists of a *t*-test of the hypothesis of no difference in response between the control population and a population dosed with strontium-90. Dr. Finkel accepts the null hypothesis at the 10 per cent significance level ("10% probability level or higher") for the three lowest-dosed experimental groups, and considers that this acceptance constitutes "evidence that there might be a threshold" or that "a threshold . . . may lie between 4.5 and 44  $\mu\text{c/kg}$ ."

It constitutes nothing of the kind. It is clear that the width of the acceptance

region for the null hypothesis (shaded region in Figs. 3 and 4 of Dr. Finkel's paper) should vary inversely as the square root of the number of animals in the experimental groups, assuming approximate normality of the death-rate curve  $g(t)$ , as Dr. Finkel must have done in applying the  $t$ -test. The threshold for which she finds "evidence" in the experiments is thus no threshold at all but simply a reflection of the statistical uncertainty of her information. It is clear that she could have found "evidence" of this sort for a threshold at any arbitrarily large radiation level (perhaps short of what would produce acute radiation sickness) by simply using few enough animals in her experiments.

The fallacy in Dr. Finkel's statistical argument is a failure to control the probability of type-II error of her test. Type-II error<sup>2</sup> is acceptance of the null hypothesis when it is in fact false. Consideration of the type-II error requires consideration of the alternative to the null hypothesis, which in this case is the theoretically likely linear response at low doses. If we use for the slope  $d\Delta/d\alpha^*$  at  $\alpha^* = 0$  of the life-shortening response at low doses the value obtained above (eq. (13)) from a study of Dr. Finkel's results, namely,  $d\Delta/d\alpha^* = 0.14\%$  ( $\mu\text{c/kg}$ )<sup>-1</sup>, and if we assume that Dr. Finkel's  $t$ -test acceptance region is appropriate to a one-tailed test at  $\alpha^* = 8.9 \mu\text{c/kg}$ , the highest experimental value for which the null hypothesis was accepted, then we can calculate the probability of type-II error. It is 85 per cent. This means that if there exists in fact no threshold at  $8.9 \mu\text{c/kg}$ , Dr. Finkel's test would nevertheless have produced "evidence" for one in 85 experiments out of every 100 experiments performed. On the other hand, if there were in fact a threshold, the test would deny it in only 10 per cent of the experiments. Evidently the test is worthless as a proof of the existence of a threshold at this dose level (or lower, for which the probability of type-II error approaches the maximum that is possible, 90 per cent, for a 10 per cent probability of type-I error).

It is incumbent upon those who would extrapolate their threshold conclusions from 150 mice to  $3 \times 10^8$  human beings that they demonstrate the existence of a significant experimental departure from the theoretically likely linear response, because although the existing burdens of strontium-90 are low, the number of individuals involved is very large, and the harmful consequences of proceeding on an unfounded assumption of a threshold are great.<sup>6</sup> As we have shown above, Dr. Finkel's results are in complete harmony with a linear law; in fact, the agreement between the linear law and the experimental results is better than could have been expected on the basis of the width of her null-hypothesis acceptance region.

As an alternative to the statistical tests, Dr. Finkel determines a threshold by extrapolating the experimental life-shortening curve. She states: "Since the [life-shortening] values for 1.3, 4.5, and  $8.9 \mu\text{c/kg}$  do lie along a straight line when plotted semilogarithmically, it may be argued that they represent true departures from the control value. An extension of this straight line crosses the control value at  $0.4 \mu\text{c/kg}$ ." It is difficult to see why the semilog plot rather than some other should be used for the extrapolation. But in fact an extrapolation of any kind is groundless. The three response values lie within less than half the range of probable error (within  $-1/2$  P.E. to  $+1/2$  P.E.) of the difference  $d$  between experimental values of  $\Delta$ , as determined from the width of the null-hypothesis acceptance region ( $\sigma_d = 5.5$  per cent). If it is not obvious that no non-zero regression slope determined from these points can have any statistical significance, one can show<sup>7</sup> that

the standard deviation of the regression slope estimator derived from the semi-logarithmic plot is 2.2 times the estimated slope itself. If the semilogarithmically linear relation of the three points can be ascribed to anything but chance, then all of Dr. Finkel's statistical arguments are false. It is hard to imagine how two such mutually contradictory "proofs" could be advanced at one time.

There are other statistical points in Dr. Finkel's paper that merit scrutiny. In our discussion of her results we have had to rely on the correctness of the null-hypothesis acceptance region that she presents, but there are serious reasons for doubting its correctness. The width of the acceptance region corresponds to the estimate  $\hat{\sigma} = 284$  days for the standard deviation of the death-rate function  $g(t)$ , if it applies to a one-tailed test on the difference between the life-shortening values obtained from two experimental groups of 150 animals each. On the other hand, Dr. Finkel's statement<sup>8</sup> that groups of 1393 animals would have been required to establish as significant at the 1 per cent level the difference observed (2.5 per cent) at the lowest dose corresponds to  $\hat{\sigma} = 171$  days, a gross discrepancy. The latter value, we note, agrees reasonably with the values  $\sigma = 161$  days from the Gompertz relation or  $\hat{\sigma} = 191$  days from the agreement between experimental data and our theoretical curve.

It is clear that since the number of animals differs from one experimental group to another in Dr. Finkel's experiments, the null-hypothesis acceptance region cannot have width independent of injected dose  $\alpha^*$ , as shown in her figures. From the information given there is no way to tell to which experimental groups the test appropriately applies.

More serious is the evident fact that Dr. Finkel applies the same acceptance region indiscriminately to the three very different sets of experimental data represented by her curves A, B, and C. It seems likely that the test was designed to handle the life-shortening data (curve A), because a  $t$ -test would not be inappropriate to life-span data, since the death-rate function  $g(t)$  is (rather crudely) Gaussian. A statistical analysis of the curve-C data would be difficult, because the experimental statistic  $\tau$  (20 per cent incidence time) is cumbersome to handle mathematically, as is evident in our discussion. But it is easy to show that Dr. Finkel's acceptance region is entirely inapplicable to the curve-B data ("proportion of animals that survived the latent period of 150 days and then died with osteogenic sarcomas").

The number of bone-cancer deaths in populations of a given size during a given time interval will be Poisson-distributed, if we neglect variations in population size due to deaths during the first 150 days, which is legitimate, as can be seen from Table 1 or from numbers given by Dr. Finkel, which show that the control group still contained close to 150 animals at  $t = 150$  days. Whatever the low-dose regression function for curve B, it is clear from Dr. Finkel's Figure 4 that the expected number  $\xi$  of bone-cancer deaths is close to 3 for groups of 150 animals not dosed with strontium-90. To find acceptance regions for the null hypothesis of no significant difference in the number of such deaths between the control population and a dosed population of equal size we therefore find the value of the difference  $\delta$ , such that the probability of type-I error (one-tailed test) is  $P$ :

$$1 - P = e^{-\xi} \sum_{n=0}^{\xi-\delta} \frac{\xi^n}{n!} + e^{-\xi} \sum_{n=\xi+\delta}^{\infty} \frac{\xi^n}{n!} \quad (27)$$

The results of a numerical evaluation of equation (27), in case  $\xi = 3$ , are  $P = 0.10$ ,  $\delta_P = 2.6$ ;  $P = 0.01$ ,  $\delta_P = 5$ ;  $P = 0.001$ ,  $\delta_P \cong 8.5$ . Using the fact that the observed number of control deaths was 3 (2 per cent of 150), we find that the upper limit of the acceptance region at 10 per cent significance level is 3.7 per cent of 150. From Dr. Finkel's Figure 4 we therefore see that the highest strontium-90 dose that produced a "statistically non-significant increase" in the number of bone-cancer deaths is 8.9  $\mu\text{c/kg}$ , not 200  $\mu\text{c/kg}$  as stated by her. Her acceptance region represents for curve B a test having 0.1 per cent probability of type-I error. Her entire discussion of the statistical significance of the curve-B data is erroneous.

*The Proper Testing of Evidence for a Threshold.*—From the above discussion it is clear that a valid statistical test of the null hypothesis of "no response" at a given radiation level or a given dose of strontium-90 must use the type-II error as the basic parameter, rather than the type-I error, as is employed in the standard "cook book" tests, which are designed basically for application to the manufacture of goods. Alternatively stated, the null hypothesis that must be tested in the standard way is the hypothesis that the observed response values are in accord with a linear response curve at low doses.

Our analysis of Dr. Finkel's data for mice enables us to estimate reliably the linear decrease in life expectancy for low doses of strontium-90, and it is therefore possible for us to determine how many animals would have to be used in an experiment in which the mean lifetime of a control group is compared with the mean lifetime of a dosed group in order to establish the existence of a threshold at or above the dose used. We may consider two types of test: (A) the "minimal" test, that is, the test that requires as few animals as possible; (B) the "most powerful" test, which minimizes the probability both of type-I and of type-II error.

The null-hypothesis "no response" for test A is to be accepted if the dosed group exhibits no decrease in life expectancy, or an actual increase, when compared to the control group. Clearly this acceptance region makes the test minimal, because the probability of type-I error is 50 per cent, so that the test gives a neutral decision in case a threshold actually exists. If the number of animals used is greater than required for test A, then a decision as to the existence of a threshold will be more often right than wrong, in case that the threshold does actually exist. At the same time we can protect ourselves adequately against the serious alternative possibility by suitably choosing the type-II error.

Since the expected decrease in life expectancy for the dosed group is  $\alpha \cdot d\Delta/d\alpha|_0$ , the type-I and type-II errors are simultaneously minimized, and made equal, by choosing as the upper limit of the acceptance region for test B a decrease in life expectancy of  $1/2 \alpha \cdot d\Delta/d\alpha|_0 = 0.63\% \cdot \alpha$ , where  $\alpha$  is given in  $\mu\text{c/kg}$  retained in the body.

Since the expected decrease is proportional to  $\alpha$ , the number of animals  $M$  required for the control group, if an equal number is used for the dosed group, is given by

$$M = \frac{\nu}{\alpha^2} \quad (28)$$

where  $\nu$  is a constant that depends on the type of test (A or B), on the probability of type-II error, and on the standard deviation  $\sigma$  of the natural death-rate function

$g(t)$ . Because  $M$  proves in all cases of interest to be large, it is adequate to use the normal distribution in computing the constants  $\nu$  in equation (28), owing to the Central Limit Theorem.

TABLE 2  
VALUES OF THE CONSTANT  $\nu$  IN EQUATION (28)

|                                               | Type of Test     |      |                        |       |
|-----------------------------------------------|------------------|------|------------------------|-------|
|                                               | A<br>("Minimal") |      | B<br>("Most Powerful") |       |
| $\sigma$ (days).....                          | 284              | 170  | 284                    | 170   |
| 10 per cent probability of type-II error..... | 4560             | 1630 | 18240                  | 5520  |
| 1 per cent probability of type-II error.....  | 14950            | 5360 | 59900                  | 21440 |

Using all of these principles, we have computed the coefficients  $\nu$  for the various circumstances shown in Table 2. In particular we compare the results for  $\sigma = 284$  days, derived from Dr. Finkel's acceptance region, with the results for  $\sigma = 170$  days, which seems most reasonable on the basis of the previous discussion.

The numbers  $\nu$  given in Table 2 are equal to the number of animals in the control and in the dosed groups required to establish the existence of a threshold at  $\alpha^* = 9.1 \mu\text{c/kg}$ , just above the highest injected dose (8.9  $\mu\text{c/kg}$ ) for which Dr. Finkel accepted the hypothesis that a threshold exists. The numbers of animals used in her experiments were too small by factors of 10 to 400, for the conclusion that she reached. By solving equation (28) for  $\alpha$  we may compute very simply the lowest threshold  $\alpha^*$  that could have been recognized with statistical significance in her experiments, assuming that 150 animals were used both in the control group and in the dosed groups, which in general was not the case (fewer were used). These values of  $\alpha^*$  are 91 and 54 for test A and 181 and 109 for test B (in each case for  $\sigma = 284$  days and 170 days, respectively). It is clear from the experimental data that no threshold exists at any of these levels, and accordingly we are required to conclude that Dr. Finkel's data show that there is no threshold large enough to have been recognized with statistical significance from her data.

*Conclusions about Effects on Man of Strontium-90 from Fallout.*—We now turn to the discussion of Dr. Finkel's conclusion that the present contamination with strontium-90 from fallout is so very much lower than the "threshold" levels that it is extremely unlikely to induce even one bone tumor or one case of leukemia.

This statement by Dr. Finkel is shown by the argument given above to have no justification whatever from her experimental results, obtained with 150 mice or fewer in her control group and injected groups. We may ask how many mice would be needed in each group in order to permit Dr. Finkel's statement to be made with statistical significance (or to be shown to be false).

The present average body burden of strontium-90 in the world's population is about 0.0002  $\mu\text{c}$  per person. This corresponds, with Dr. Finkel's conversion factor (5 to 10  $\mu\text{c}$  per 70-kg man equivalent to 1  $\mu\text{c}$  retained per kg for mice) to a retained dose  $\alpha = 0.00002$  to 0.00004  $\mu\text{c/kg}$  in mice. Hence in order to justify Dr. Finkel's statement evidence would be needed that the mouse threshold is as great as about 0.00004  $\mu\text{c/kg}$ ; that is, we must place  $\alpha$  in equation (28) equal to 0.00004  $\mu\text{c/kg}$ . From the values of the constant  $\nu$  in Table 2 (we use the values for  $\sigma = 170$  days, which we believe to be better than those for  $\sigma = 284$  days) we find  $M = 1 \times 10^{11}$  for the "minimal" test and  $3.4 \times 10^{12}$  for the "most powerful" test with 10 per cent type-II error, and  $3.3 \times 10^{13}$  and  $13.5 \times 10^{12}$ , respectively, with 1 per cent type-II

error. We hence conclude that a study like that made by Dr. Finkel would have to use a much greater number of mice than the number of people in the world, in order to provide evidence that would justify her extreme statement to be made with statistical significance.

This conclusion is, of course, not at all unexpected. The difficulty of detecting by statistical methods an effect that causes a small increase in the annual number of deaths among the world's population is well known. For example, let us assume that the average number of deaths per year is 50 million. The statistical fluctuations from this average from year to year are measured roughly by the square root of this number, 7000; and accordingly a study of a larger population would be needed to show with statistical significance the existence of an effect resulting in an additional 1000 deaths per year (the rough estimate of the world-wide effect of the present body burden of strontium-90 from fallout, if there is no threshold). The same number of mice would be needed to test the equivalent effect in mice.

**Summary.**—We have developed methods of theoretical analysis of the results of experimental studies of the effects of injection of radioactive substances into animals on their life expectancy and on the incidence of tumors. These methods have been applied to the data reported for mice by Dr. Miriam P. Finkel, and it has been shown that her conclusion from these data that it is extremely unlikely that the strontium-90 from the fallout from nuclear weapons tests will induce even one bone tumor or one case of leukemia in human beings is completely unjustified.

\* This paper is a contribution from the Division of the Geological Sciences (No. 908) and the Division of Chemistry and Chemical Engineering (No. 2421) of the Institute. A brief account of the work has been published by us (Letter to the Editor, *The New York Times*, Nov. 16, 1958), and a reply has been made by Dr. Finkel (*ibid.*, Nov. 30 1958).

<sup>1</sup> M. P. Finkel, *Science*, 128, 637, 1958.

<sup>2</sup> E. B. Lewis, *Science*, 125, 965, 1957.

<sup>3</sup> H. Jones, *The Nature of Radioactive Fallout and Its Effects on Man* (Washington, D. C.: Government Printing Office, 1957), p. 1109.

<sup>4</sup> Jahake and Emde, *Tables of Functions* (New York: Dover Publications, 1945), pp. 1-9.

<sup>5</sup> A. M. Mood, *Introduction to the Theory of Statistics* (New York: McGraw-Hill Book Co. Inc., 1950), p. 247.

<sup>6</sup> L. Pauling, *No More War!* (Dodd-Mead & Co., 1958).

<sup>7</sup> Mood, *op. cit.*, pp. 292-294.

<sup>8</sup> Finkel, *op. cit.*, pp. 638-639.

## EXTRACTS FROM "THE LATE EFFECTS OF RADIOACTIVE STRONTIUM ON BONE"

### HISTOGENESIS OF BONE TUMORS PRODUCED IN RATS BY HIGH $\text{Sr}^{90}$ DOSAGE

(By Stanley C. Skoryna, M.D., and David S. Kahn, M.D.)

#### SUMMARY AND CONCLUSIONS

Radioactive strontium ( $\text{Sr}^{90}$ ) was administered intraperitoneally in 6 doses at monthly intervals to 180 noninbred rats. The initial dose was 0.9  $\mu\text{c}$ . per gm. of body weight; this was followed by 5 doses of 0.7  $\mu\text{c}$  per gm. of body weight each. The investigation was designed to study the late effects on bone of high doses of radioactive strontium. The rat was chosen as the experimental animal because the growth epiphysis does not close in this species of animal. This provided an opportunity to study the effects of radioactive strontium deposition during relatively active osteogenesis.

One hundred animals (63 percent) survived the minimal latent period (188 days), before the first gross tumor was observed; of these, 89 animals developed grossly palpable tumors of the long bones or the spine. Neoplastic changes were found, on microscopic examination, in all animals surviving the minimal latent period. The majority of these animals had pulmonary metastases.

In addition to the tumors, the basic changes observed were: (1) disturbance of osteogenesis; (2) fibrosis of the marrow; and (3) cellular proliferation. The changes in the bone were maximal in the metaphysis in relation to the epiphyseal cartilage growth, corresponding to the areas of most active osteogenesis. It appears that changes observed were due to a local effect of  $\text{Sr}^{90}$  deposition in the mineral lattice of bone. The histological changes seen at this late stage represent the results of several mechanisms: (1) primary effect of irradiation; (2) sequelae of mechanical weakening of the area secondary to the disturbed osteogenesis; and (3) physiological remodeling sequences in response to this nonspecific metaphyseal weakening.

It is suggested that the bone-seeking isotopes are most dangerous if the animal is exposed during a period of relatively active osteogenesis, but not rapid turnover, when the isotope would be incorporated into the mineral phase and retained for a long period. In humans this would appear to be during the final stages of bone growth (i.e., puberty) and during the healing stage of fractures.

Microscopic foci of cellular proliferation in the marrow and neoplastic lesions of various sizes were found. It is suggested that the minute foci of proliferating cells represent the earliest stages in the development of tumors. The advancing edges of larger tumors were undifferentiated and resembled these minute foci. All types of osteogenic sarcomas seen in human pathology were observed, including the classical osteogenic, osteoid, and telangiectatic types. A few tumors showed a primarily chondrosarcomatous or fibrosarcomatous differentiation.

It is suggested that the factors affecting differentiation of these tumors are not necessarily the same as those inducing them—namely, irradiation effects.

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# AN EPIDEMIOLOGICAL STUDY OF CONGENITAL MALFORMATIONS IN NEW YORK STATE

THE ASSOCIATION OF ELEVATED MALFORMATION RATES IN MAN WITH RESIDENCE IN AREAS CONTAINING NATURAL MATERIALS WITH RELATIVELY HIGH CONCENTRATIONS OF RADIOACTIVE ELEMENTS.

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Congenital malformation rates, based on information entered on birth and death certificates, are higher in certain areas of New York State than in others. Available geological data indicate a correlation between areas with high malformation rates and geographical locations containing natural materials with relatively high concentrations of the radioactive elements.

The initial clue to this association was uncovered by the senior author in 1954 after his attention was directed to an "unusually large number of cleft palate patients" who were residents of a northern New York county. Information obtained from the Office of Vital Statistics of the New York State Department of Health showed relatively high reported rates for all congenital malformations in townships within one portion of this county. Data from the Atomic Energy Commission pertaining to a reconnaissance of radioactive rocks of the Hudson Valley and Adirondack Mountains (1) revealed that the townships with a high reported malformation rate were located in an area with igneous bedrock outcrops having relatively high levels of radioactivity and an average range of equivalent uranium content between 0.003 and 0.004 percent.

A review of the reported congenital malformation rates for all townships within upstate New York indicated that additional areas with elevated rates

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were located primarily in the Adirondack Mountains, Hudson Highlands and portions of the Allegheny Plateau section of southern New York. These areas also contain igneous or black shale bedrock having relatively high radioactivity levels (2) (3) (4) (5) or glacial deposits of these materials associated with advances and retreats of the ice sheets.

As a result of these leads, an epidemiological study was initiated in upstate New York with the following objectives:

1. Determination of the incidence of congenital malformations reported on birth and death certificates by county, city, township and village;
2. Determination of the type, amount and distribution of natural materials with relatively high concentrations of the radioactive elements;
3. Determination of the association, if any, between the incidence of congenital malformations and the distribution of such materials; and
4. Evaluation of the roles which known teratogenics, including radiation, may have had in producing congenital malformations within relatively high and low malformation rate areas.

#### 1. THE INCIDENCE OF CONGENITAL MALFORMATIONS.

##### A. Number and types of malformations reported on birth and death certificates.

Birth and death certificate information was used exclusively for the purpose of compiling congenital malformation data. Information from the Medical Rehabilitation (physically handicapped children's) Program in New York State was not utilized because of the high degree of selection of cases under the program. Stillbirth data were also excluded because of the unreliable nature of the reported causes of stillbirth.

The birth certificate used in upstate New York contains on the reverse side a confidential medical supplement. Attending physicians are asked to answer a number of questions, including "Congenital malformation of infant: No ☐ Yes ☐ If yes, describe". This question is answered in the negative or with a specified

anomaly on 90 percent of the certificates. Recorded anomalies are subsequently classified by the Office of Vital Statistics as to congenital malformation type according to the International Statistical Classification of Diseases, Injuries, and Causes of Death. Non-physician deliveries in New York State are for all practical purposes non-existent.

The number of malformations reported on birth certificates is inevitably incomplete, since a certificate must be filed not later than five days after birth, and some malformations are not diagnosed within this time. For the years 1948-1955, all certificates of death for children under five years of age, stated to have been born in upstate New York, were also available and were matched to their corresponding birth certificates. Malformations which were reported only on the death certificate were added to those reported on the birth certificates.

Table 1 shows, for each of the years 1948-1955, the number of live births to residents of upstate New York; the number of these births with malformations reported on the birth certificates; and the number of children with malformations unrecorded at birth but subsequently reported by death certificate. This latter information is further differentiated for individuals who at death were under one year, or from one to four years of age. The information for the one to four age group is, of course, incomplete for children who were born in 1951-1954 and wholly lacking for those born in 1955.

For the entire period, there were 13,248 births with malformations reported by birth certificate, and 3,121 by death certificate only -- a total of 16,369 individuals, representing an average annual incidence of 13.2 congenital malformations per 1,000 live births.

Table 2 shows the total number of cases for the period 1948-1955 by general malformation categories according to whether reported on the birth certificate, or by death certificate only. When two or more malformations appeared on the birth certificate, the case was allocated to the more serious category. When a

child with a malformation reported on its birth certificate died from another malformation, it was classified to the malformation reported as the cause of death.

#### B. Malformation rates for cities, villages and towns.

Births recorded Upstate are allocated to the usual place of residence of the mother. The 1948-1955 births and recorded malformations were tabulated by residence for each city and village over 2,500 population and for each township, exclusive of any villages over 2,500 located within the township. Rates per 1,000 live births were then computed for each of the areas.

There is little state-wide difference in the incidence of malformations for urban and rural areas. The rates are 12.9 per 1,000 live births for cities over 10,000, 13.4 for incorporated communities 2,500-10,000, and 13.5 for rural areas. In all, 186 out of 942 townships have rates of 20.0 or more. These are shown on the map in Figure 1. While these are scattered throughout the State, seven counties have no township with a rate this high, and 12 counties have only one each. In many counties the high rates are in adjacent townships, forming a cluster. For example, in St. Lawrence County, seven of the eight high rate townships are adjoined and are adjacent to the one high rate township in Lewis County. Similar clusters are also located in the Adirondack portion of Essex, Franklin, Warren and Saratoga counties; in the Catskills; and in the counties of the Allegheny Plateau. All of the counties with no high rate townships lie in the Erie-Niagara-Mohawk plain, in the Hudson Valley lowlands and on Long Island.

#### II. TYPE, AMOUNT and DISTRIBUTION OF NATURAL MATERIALS WITH RELATIVELY HIGH CONCENTRATIONS OF THE RADIOACTIVE ELEMENTS.

All rocks contain at least minute quantities of the radioactive elements. The most important of the naturally occurring radionuclides are  $C^{14}$ ,  $K^{40}$ ,  $Ra^{226}$ ,  $Th^{232}$ ,  $U^{238}$  and the decay daughters of the last three nuclides. (6)

Rocks containing these materials may occur as bedrock or as less massive, fragmentary products of erosion. Large quantities of these smaller rock particles are associated with extensive morainal deposits of the glacial ice sheets.

Radionuclides from rocks, or their erosion products, may leach into ground waters, be utilized by plant life or be disseminated into the atmosphere as gases or as particulate matter. The amounts of these materials in the environment are usually greater when associated with rocks with relatively high concentrations of the radioactive elements.

#### A. Bedrock.

Most of the common rock types occur within the boundaries of New York State. These include igneous and metamorphic rocks, and the sedimentary shales, limestones and sandstones. The general distribution of these bedrock materials within New York has been extensively mapped by geological workers and is illustrated in Figure 2. (7)

Generally, more silicic igneous rocks, such as granite and syenite, have a higher concentration of radioactive elements than do less silicic igneous types such as basalts, or the sedimentary rocks. Among the sedimentary rocks, limestones and sandstones are relatively low in radioactivity, while shales are somewhat higher. Organic black shales have been found to be especially high. (4) Differences in the occurrence of radioactive elements in granite versus sedimentary rock types are in the magnitude of as much as 5 to 1 as illustrated in Table 3. (8)

Most of the area of what is known as the Adirondack Province is underlaid by igneous and metamorphic rocks. Outside of this region their only extensive occurrence as surface rock is in the Hudson Highlands, a narrow strip in the southeastern part of the State that includes Putnam County and part of Orange and Rockland counties.



The Atomic Energy Commission has published four reports dealing with reconnaissance of radioactive rocks in New York State. (1) (2) (3) (5) Vickers also made a study of the radioactivity of various sedimentary rocks in Central New York. (4) Additional unpublished studies of the organic black shales have been made by staff members of the New York State Geological Survey.

The areas with the greatest concentrations of materials with unusually high radioactivity levels were found by Marten and McKeown (1) to occur in the northwestern and southeastern Adirondacks where there are numerous contacts between gneisses of the Grenville series and the granodiorite complex. The Hudson Highland gneisses were found by McKeown (3) to have an average percentage of equivalent uranium from 0.003 to 0.004 percent which is higher than the 0.002 percent that is considered to be normal.

A statewide compilation of these data is illustrated in Figure 3. This includes mapping of surface outcrops of organic black shales containing at least 0.003 percent equivalent uranium. Shale outcrops with radioactivity levels elevated but lower than that for black shale are also indicated. The underlying igneous rock formations of the Adirondack and Hudson Highland provinces are shown where relatively high levels of radioactivity are present in scattered exposures. Black shale formations also underlie a considerable part of the Hudson Valley area. Here the formations with elevated radioactive content outcrop in an irregular manner which has not been mapped in detail for the entire area.

These maps include all generalized radiological information available at the time of report preparation. It should be emphasized, however, that the data are not complete. Little or no information based on field measurements is available for much of the unmarked areas. The absence of data does not, therefore, necessarily indicate the complete absence of rocks with relatively high levels of radioactivity. Spot anomalies may be expected in many areas. Major surface exposures of such materials, however, may be assumed to be recorded.

#### B. Glacial Material

Except for a small area in southern Cattaraugus County, all of New York State has been glaciated. During the Pleistocene epoch of geologic time when glaciation was occurring in North America, at least four separate ice advances took place. Of these, the last, or the Wisconsin advance, was the most important in New York State in laying down the glacial deposits which now underlie the land surface.

The ice moved generally southward into New York from centers of accumulation to the north. At its maximum, the glacier was probably several thousand feet thick over much of the State. During its movement, the glacier abraded the underlying rock and incorporated huge quantities of it into the ice. When the ice retreated by melting, this material was left as a deposit over the land in various forms. Glacial till, or boulder clay, an unsorted deposit, was left by the melting ice over most of the State. The retreat to the north was marked by several periods of equilibrium of ice advance and melting so that the ice front remained stationary long enough to pile large amounts of debris, called recessional or terminal moraines, at the static ice front.

Melt water draining to the south through valleys which had been widened and deepened by the glacier deposited large amounts of glacial outwash in them. These valleys are located primarily in the southern part of the State in the Allegheny Plateau.

When the edge of the ice was melted back to a position north of the drainage divide, the bulk of the glacier blocked the drainage and the melt water became ponded between the glacier edge and the higher land of the divide. Debris was washed into these ice dammed lakes with a sorting of the rock material during deposition which produced deposits of fine silt and sand. These latter types of deposits are extensively developed in the Hudson Valley north of Kingston, in the Black River Valley which is located along the southwestern boundary of the Adirondacks, over the lake plain between Lake Ontario and the front of the Allegheny Plateau, and on the St. Lawrence lowland.



Composition of the different types of glacial deposits is extremely variable. Composition is, however, directly related to the nearby bedrock which usually supplied the predominant material in the deposit. Shales, having been formed originally from clay material, and being generally less resistant than other rock types, yielded glacial deposits with much clay. Igneous rocks eroded by the glacier are deposited predominantly as sands and gravels or generally coarse debris. The relative resistance of the rock determined the persistence of the rock in the drift. The igneous rocks, being the hardest, are often found hundreds of miles from the outcrop.

Depth of deposits is also variable. The more extensive deposits are located in the valleys and where material was deposited in lakes or in the sea, (water-laid). Generally, deposits are thin over uplands and on steep slopes. Accurate information as to depth of deposits is lacking for much of the State.

Radioactivity levels for glacial material are directly related to the type and level of the parent bedrock and the composition of the overburden. McKee (3) found abnormally radioactive glacial material up to ten miles from the bedrock source. The fine sands and silts of water-laid deposits are generally lower in radioactivity than the till, or ice-laid morainal material, in the same area.

A state-wide mapping of the distribution of glacial material is illustrated in Figure 4. This represents a compilation of available data from various authorities. Fairchild (9) mapped glacial deposits for the central and western parts of the State and his maps were used extensively. Mapping of moraines in the eastern part of the State was spotty and the data were gathered, where available, from various authors. Major terminal and recessional moraine deposits are mapped under the designation of "drift border". General till cover was not included in the mapping because of its wide distribution.

### III. ASSOCIATION OF THE INCIDENCE OF MALFORMATIONS WITH THE DISTRIBUTION OF MATERIALS WITH RELATIVELY HIGH CONCENTRATIONS OF RADIOACTIVE ELEMENTS.

#### A. Classification of townships on the basis of geological data.

Before the malformation data for all local areas became available, a classification of all townships and cities in upstate New York was made pertaining to the probable or unlikely presence of extensive quantities of materials with relatively high concentrations of radioactive elements. The classification of "probable" was made when a township or city fell within one of the three following categories:

1. Igneous bedrock areas,
2. River valleys in the Allegheny Plateau, and
3. Terminal or recessional moraine areas with igneous or black shale outcrops occurring within a twenty-five mile distance to the north of the center of the city or township.

Townships and cities not falling within these three categories were classified as "unlikely".

The igneous bedrock category was selected because this rock type contains the highest concentration of radioactive elements found in natural materials within New York State. River valleys in the Allegheny Plateau were included because of the extensive glacial deposits in these locations with the presence of both igneous and black shale components. Morainal areas were also included, despite smaller deposits on upland slopes, when a confirmed outcrop of igneous or black shale material was present within an arbitrary twenty-five mile distance from the direction of glacial ice movement. The twenty-five mile distance was selected on the assumption that the great majority of all radioactive glacial materials present would have been derived from bedrock sources within this area. Areas with mapped water-laid glacial deposits were excluded because of the relatively lower radioactivity levels of these materials.

Classifications were based exclusively on the state-wide maps of bedrock and glacial material illustrated in Figures 3 and 4. Townships were classified as "probable" only when more than one-half of the total township area or the major population centers were associated with one of the designated categories.

Additional state-wide classifications were made as to the presence of bedrock exposures of igneous or black shale material within a ten mile distance to the north of the center of a city or township. A more restrictive ten mile distance was used in this classification because of the definitive findings by McKeown (3) of abnormally radioactive glacial materials as far as ten miles from a bedrock source. A classification was also made based on the presence of any mapped glacial deposits and whether these covered more than one-half of the area of the township or the population centers.

#### B. Malformation rates for townships classified according to geology

Malformation rates among children of residents of all urban and rural areas, classified as to the probable or unlikely presence of extensive quantities of natural materials with relatively high concentrations of the radioactive elements, are shown in Table 4. For all "probable" areas the rate is 15.1 per 1,000 births, as compared with the rate of 12.8 for the "unlikely".

If geology is a factor in the incidence of malformation, one would expect the association to be less marked in the urban than in the rural areas, where there should be greater exposure to natural materials. Table 4 shows that this is the case with rates for the "probable" and "unlikely" rural areas being 15.8 and 12.9, as compared with the corresponding urban rates of 14.1 and 12.8.

Within the rural areas, the presence of igneous bedrock is associated with a rate of 17.5. River valleys in the Allegheny Plateau and/or drift borders (terminal or recessional moraines) have a rate of 15.4. For river valleys the rate is 15.5, and for drift border areas, 15.0.

Analysis of more detailed geological classifications of rural townships indicate that the location of a township within a river valley or a drift border area is apparently more significant than the presence of bedrock outcrops of igneous or black shale material within the township or within a distance of ten miles to the north. However, outside the river valley and drift border areas, the rates of townships with and without such outcrops are 13.4 and 12.4, respectively. Where glacial deposits have been mapped, the rates for townships in river valley and drift border areas, which are more than half covered with glacial deposits, are higher than those which are less than half covered: 18.0 vs. 15.1.

Table 5 shows malformation rates by type of malformation in the "probable" and "unlikely" rural areas. For every type of malformation, except mongolism, the rate is higher in the "probable" areas.

It is difficult to test these differences for statistical significance since their standard deviations are certainly larger than those obtained by assuming binominal distribution. It is possible however to test for the consistency of the pattern throughout the State.

Grouping the counties of the State into the six standard geographical regions shown in Table 6, we find that in each region the malformation rate for "probable" towns is greater than for the "unlikely", although the difference is very small for the Catskill-Pocono Highlands.

Of the 57 Upstate counties, 38 contain townships classified as "probable". The average difference in these counties between the rates for "probable" and "unlikely" areas is 2.9, with a standard error of .95. The probability of this difference occurring by chance is less than 3 in 1,000. In 23 counties, the rate for the "probable" townships was higher than in the "unlikely", with the average difference in the rates being 6.3. In the 15 counties where the rate for "probable" townships was lower than for the "unlikely", the average difference was 2.3. In

3 counties, all townships were classified as "probable", with an average rate of 14.3. In 16 counties, all townships were classified as "unlikely", with an average rate of 11.3.

C. Association of the incidence of malformations with geology and socio-economic status

If the association of malformation rates with geology is not an accidental phenomenon, the question arises as to what factor, or factors, might be associated with both a higher incidence of malformations and geology. One such factor is the socio-economic status of the population. Unfortunately, there are no population data from the U. S. Census available for townships sufficient to classify the townships in this regard. However, for a special study of reproductive wastage now underway in the New York State Health Department, all births for the years 1950-1952, recorded to residents of the Upstate area, were coded for occupation of the father according to the 10 digit classification employed by the Bureau of the Census. The incidence of malformations among these births is not yet available, but neonatal mortality (under 28 days) from malformations as a cause of death could be computed for single white births for each occupation group. This information is shown in Table 7.

These data show a relationship between the neonatal death rate from malformations and occupation of the father, which suggests a similar relationship between occupation (or socio-economic status) and the total incidence of malformations.

To test whether the difference in malformation rates between "probable" and "unlikely" areas could be due to differences in the occupation of the father, as stated on the birth certificates, punch cards for the 1952 births to residents of the rural areas of 20 non-metropolitan counties were selected for tabulation. These included all the counties in the Adirondack Highlands and the Northern Allegheny Plateau, except the metropolitan county of Albany. These were divided into residents of "probable" and "unlikely" areas, and each group tabulated into the five occupation categories shown in Table 7.

Applying the malformation death rates prevailing Upstate in 1950-1952 to each of these occupation groups, the expected death rates for the "probable" and "unlikely" areas are 2.95 and 3.00 respectively. Differences in occupational distribution could thus not account for a higher death rate from malformations in the "probable" areas of these counties.

The incidence of malformations as reported on birth and death certificates for these areas in 1952 was also obtained. For all births in the "probable" and "unlikely" areas, the malformation rates were 16.4 and 13.3. For each occupation group the rate was higher in the "probable" than in the "unlikely" area, except for the group "service workers, laborers, and occupation not reported". The greatest difference was for farmers and farm laborers: 21.6 vs. 12.4.

D. Association of the incidence of malformations with geology and type of public water supply

In areas of probable presence of extensive quantities of radioactive materials, one would expect relatively higher levels of radioactivity in water supplies derived from ground sources (wells and springs), than in those derived from large surface waters (lakes and rivers).

There are 555 communities under 10,000 population in New York State, 499 of which are served by public water supplies. The sources of water for these systems include 255 from ground waters, 72 from lakes and rivers, 83 from brooks and streams, and 89 from mixed sources. (10)

Table 8 shows the births, malformations, and malformation rates for the residents of these communities, classified by type of supply according to their location in areas of probable or unlikely presence of extensive quantities of radioactive materials. In the "probable" areas the rate is highest, 16.9, in those communities deriving their water supply from wells and springs, and lowest, 12.4, in those utilizing large surface waters. In the "unlikely" areas, the rates

differ very little by source of supply, with those communities which derive their supply from wells and springs having a rate of 12.9, and from large surface waters, 11.9.

#### IV. EVALUATION OF THE ROLE OF POSSIBLE ETIOLOGICAL AGENTS IN PRODUCING CONGENITAL MALFORMATIONS IN AREAS WITH ELEVATED MALFORMATION RATES.

An epidemiological field investigation was undertaken in an attempt to obtain information as to differences in the frequency of occurrence of known etiological factors between relatively high and low malformation rate townships. Comprehensive family interviews were carried out and more detailed geological field studies were made of these areas. Preliminary measurements were also made of external radiation levels and the radioactivity of water supplies. The number of cases of rubella reported during each of the years 1949-1955 in the townships selected for field study was compared with the distribution of malformation cases during the same period. Possible biases in the malformation rates due to different reporting practices by hospitals, and the role of sampling variation in the selection of high and low rate townships for special duty, were also evaluated.

##### A. Selection of areas for field study

Groups of four or more contiguous rural townships with unusually high malformation rates were selected in different parts of the State to obtain approximately 300 families with malformed children recorded on birth or death certificates during the years 1950-1955. Rates for the 55 individual high rate townships selected ranged from 14.6 to 66.7 per 1,000 live births. Groups of four or more contiguous low rate townships were also selected to obtain an equal number of families with malformed children. These townships were located either adjacent to the high rate areas or were in sections of the State with predominately low rate townships.

The malformation rates for the 108 low rate townships ranged from 0 to 16.9 per 1,000 live births. The slight overlapping of rates of the high and low

rate township groups is due to the inclusion of several normal rate townships with contiguous groups of both high and low rate townships. These townships were included because of their small populations, the questionable statistical significance of their rates and their location as part of what appeared to be an otherwise uniform grouping of relatively high or low rate townships. The location of the 163 townships selected for study is shown in Figure 5.

For the townships selected, comparable malformation data for the four year period 1944-1948 were obtained to confirm the high or low rate grouping. For the high rate towns, the rate for the earlier period was 16.3; for the low rate towns, 11.1. This would suggest that the malformation rates of a substantial number of the high rate towns were "truly" high, and not merely the result of chance variation due to the small numbers involved.

The possibility that the rates in the high and low rate areas might reflect different reporting practices on the part of physicians and hospitals was also considered. Punch cards for all births to residents of the selected areas for one year, 1952, were obtained and tabulated according to the place of birth. Births occurred in 132 different hospitals. In 63 of these hospitals, births were recorded to residents of both high and low rate townships. In these 63 hospitals, the malformation rates associated with residents of high and low rate townships were 27.8 and 9.6 respectively. For deliveries in the same 63 hospitals to women residing in townships not included in the field study areas, the rate was 12.7. From this, it appears extremely unlikely that reporting practices alone could account for the differences in malformation rates between high and low rate areas.

##### B. Demographic data for field study areas

All births to residents of the field study areas for one year, 1952, were tabulated according to birth weight, age of mother, age of father, number of previous children ever born to mother, and occupation of the father. No sig-

nificant differences between high and low rate areas were found in the distribution of the births by any of these variables, although the percent of births weighing 2,500 grams or less was slightly higher in the high rate areas, 7.8 percent, than in the low rate areas, 6.6 per cent.

Neonatal mortality for 1952 was higher in the high rate area (24.2 vs. 19.0 per 1,000 live births) entirely because of the higher death rate from malformations. Mortality from 28 days up to 5 years of age was 10.8 per 1,000 live births in the high rate area, 11.6 in the low.

The stillbirth rate per 1,000 total births in the two areas for the period 1948-1955 was 16.6 in the high rate area and 16.8 in the low.

#### C. Rubella

A tabulation of the annual incidence of rubella during the years 1949-1955 in each field study township revealed no association with the incidence of malformations.

#### D. Geological field data

Of the 55 high rate townships selected, 22 were classified as igneous bedrock areas, 18 as river valley-drift border areas, and 15 as "unlikely" areas. Of the 108 low rate townships, 8 were igneous, 13 river valley-drift border areas, and 87 "unlikely".

Geological field work was carried out in the selected townships without knowledge by the worker of the high or low malformation rate status of the townships. Each town was classified as to underlying bedrock and glacial deposits, taking into account the extent of areal distribution in relation to population concentration.

Malformation rates per 1,000 live births were computed for all field study townships which had been placed in the same bedrock and glacial material categories. To reduce sampling variation, and possible bias resulting from the method of selection of field study areas on the basis of their relatively high or low rates for the period 1948-1955, rates were based upon the births for the entire period 1944-1955.

Rates did not vary by type of bedrock when the type of glacial material was held constant. Table 9 shows the rates by type of glacial material. Rates in areas with ice-laid material are consistently higher than in areas with water-laid material. Within the ice-laid category, the highest rate, 19.5, is associated with igneous glacial material. In the "mixed shale" classification, the rate is higher for those areas with extensive quantities of this material, 14.3, than for areas with limited amounts, 10.3.

#### E. Family interview data

In the high rate areas, there were 299 births with malformations recorded during the period 1950-1955. However, 13 of these were not investigated because the child was born out of wedlock or had been adopted since birth, or was in a family for which an index case had already been selected. The net total represented 286 families. In the low rate areas, 307 cases netted a total of 292 families.

For each of the index families, a control family was selected by taking from the bound volume of birth certificates the next certificate of birth to a mother resident of the same area. The location of the residences of study and control families is shown in Figure 5.

Families were interviewed by staff public health nurses to obtain detailed family residence and occupation data extending through the grandparents of children designated on the certificates. The residence history included urban-rural status, source of drinking water, utilization of natural stone as a home construction material, presence of dust as a nuisance condition, and the utilization of a home garden for family produce needs. A history of all pregnancies as well as number, birth dates, weights and health status of other children in the family was obtained. A familial history of malformations was recorded along with miscellaneous information pertaining to socio-economic level, consanguinity, national stock and

religion. Data on the nutritional status of study families were not collected because of the difficulty of obtaining reliable information and the doubtful relationship in man between malnutrition and congenital malformations.<sup>(11)</sup>

Interviews were completed for 835 families, or 72 percent of the total. Most of the families not interviewed had moved out of the area. Only 30 families refused to cooperate.

Of the 440 control individuals for whom interviews were completed, 15 were stated by the mother to have a malformation. There were 8 in the high rate area and 7 in the low, representing a rate among the total control group of 34.1 per 1,000 from interviews alone. This rate is almost three times the state-wide rate obtained from birth and death certificates, indicating the incompleteness of reporting on the birth certificates. Of the 15 cases found by interview, 6 represented conditions which could not have been detected at birth, such as pyloric stenosis and congenital dislocation of the hip. These were equally divided between high and low rate areas. The remaining 9 cases were associated with minor conditions, such as tongue tie, hammer toes, cyst under tongue, etc. The equal number of previously unknown cases found by interview among control cases in both high and low rate areas, indicates that incompleteness of reporting has not of itself been responsible for the differences in rates obtained from birth and death records.

The 15 cases found among the controls were added to the index cases, resulting in 411 cases and 425 controls. Table 10 shows the total number of live siblings of these children and the incidence of malformations among them; also the incidence of stillbirths and abortions in all sibling pregnancies. There are no consistent

<sup>11</sup> McIntosh et al report an incidence of malformations in live born infants of 7.4 percent, based upon examinations at birth, at six months and twelve months of age. (16) For infants surviving the neonatal period, the rate was 7.0, but only 43.2 percent of the malformations were observed at birth. The rate for those observed at later examination was therefore 4.0 percent, very similar to the rate reported here.

differences in any of those rates either between cases and controls, or between high and low rate areas.

Few pregnancies in families with or without malformations were associated during the first trimester with German measles, 2 vs 3; or pelvic radiation, 5 vs 3. There were no reported associations between malformations and the occurrence of other infectious diseases during the first trimester of pregnancy. There was a slight difference between the percentages of the two groups having a history of pelvic radiation following the first trimester, 11.4 vs 9.4 percent. A slightly higher percentage of women with malformed children were reported by their physicians to have experienced toxemia as a complication of pregnancy, 16.4 percent vs 13.0 percent.

The total number of reported consanguineous cousin marriages between parents or grandparents in families with and without a malformed child was 14 and 4.

Additional family history data showed a greater incidence of anomalies on both the husband's and wife's side of the family in families with a malformed child as compared to those without a malformed child. This was true also for cases of epilepsy, cerebral palsy, mental retardation, and mongolism. For diabetes, a high incidence was reported on the wife's side only.

Miscellaneous data revealed that approximately 30 percent of families in high and low rate areas reported dust as a nuisance condition, only 20 percent of all families raised more than 50 percent of their own garden produce, and that approximately one-half of all homes used stone as a building material. Igneous rock was used in one-third of all homes in the high rate areas. In 20 percent of the families in the high rate areas, and 12 percent of those in the low rate areas, there was a history of residence of some member of the family in the area over 75 years.

#### F. Radiological data

Precise and reliable measurements of radiation exposures are limited. In

connection with the present study, 38 external environmental radiation measurements were made in upstate New York by Mr. Leonard Solon, Acting Director of the Radiation Branch of the New York Operations Office, Atomic Energy Commission, and his co-workers. (13) A 20 liter ionization chamber was used in conjunction with a vibrating reed electrometer. This equipment was mounted in the rear of an automobile with all but one reading taken with the instrument being in this location. The latter reading was taken inside a church which was constructed of granite rock.

The outdoor penetrating environmental radiation levels were found to lie primarily in the interval of 8 to 12 microroentgens/hour. This represents 2.1 to 3.2 roentgens per 30-year period. The radiation associated with igneous rock areas was generally responsible for the higher levels. Appreciable departures from this range were found at points adjacent to exposed rocks having relatively high concentrations of radioactive materials. Occupational exposure associated with such materials was recorded as high as 40 microroentgens/hour. Exceptions also occurred in association with buildings constructed with materials with elevated radioactivity. A reading of 18.5 microroentgens/hour was made in the one building constructed with granite rock in which an ionization chamber measurement was made. This latter measurement was in contrast to a general environmental reading of 9.5 made outside the building.

Through the cooperation of the Atomic Energy Project at the University of Rochester School of Medicine and Dentistry, 18 water samples were analyzed for radioactivity levels by Dr. John Hursh. A description of Dr. Hursh's analysis procedures has been published. (14)

Preliminary screening measurements of water samples from both high and low malformation rate areas were made with the intent of picking up any highly radioactive ground source. A sample from a drilled well containing  $29 \times 10^{-16}$  grams per ml of Ra226 represents such a source. This sample was taken from the igneous rock area of the Adirondacks. The sample showing the next highest level at

$5.2 \times 10^{-16}$  grams was also taken from an igneous section in Putnam County, within the Hudson Highlands. These levels are in contrast to a general range of from 0.0 to  $1.7 \times 10^{-16}$  grams of radium per ml found in public water supplies. (14) Measurements of emitters from the thorium chain are not complete. Initial findings, however, reveal no evidence of substantial amounts of these emitters in the samples collected. Preliminary examinations for trace elements have not revealed any notable differences between samples from the various areas.

Radon measurements for mines in the Adirondacks which were carried out by the New York State Department of Labor and the New York Operations Office of the Atomic Energy Commission, were found to be between  $10^{-10}$  and  $10^{-11}$  curies per liter in the majority of places sampled. (12) The former levels exceed the present maximum permissible concentration of radon and radon daughter products of  $10^{-11}$  curies per liter.

Bone and tissue specimens from life time residents coming to autopsy are also being collected in certain <sup>study</sup> areas for future radiological measurements by the Atomic Energy Commission's New York Operations Office.

#### DISCUSSION:

The foregoing data represent an epidemiological fact-finding study. The associations noted are statistical in nature and represent a first step in establishing possible cause-effect relationships. It should be stressed that the associations relate to total malformation rates and the location of geographical areas containing materials with relatively high concentrations of radioactive elements. This is not tantamount to a direct relationship with external environmental radiation levels or "background" radiation.

The study and the study data are also not comparable to the studies of the effects of atomic blast radiation in Japan (15) or to the majority of animal studies dealing with ionizing radiation. The latter studies have been related almost exclusively to high-dose, external radiation administered over short

periods of time. In contrast, the environmental radiation factors herein described pertain to low dosage levels over long periods of time. With many families, the time factor has included several generations. The sources of radiation, in addition to external radiation, include internal emitters which may have been ingested with food or drinking water, or inhaled.

The data upon which this report is based relate to such a substantial number of births that most of the differences indicated would be statistically significant by whatever tests devised. However, the real significance lies in the overwhelming consistency of the pattern which is shown in the relationship of malformation rates to geology. The data are crude with factors other than chance variation operating. Some of the most convincing evidence may be found in a comparison of the maps of bedrock, glacial material and malformation rates illustrated in Figures 1, 3, and 4. Interrelationships of these three items are perhaps most readily illustrated in the area immediately to the south and southeast of Rochester. A 150 mile east-west section of the drift border of the Mankato glacial substage is associated with elevated malformation rates only in a 40 mile section which lies immediately to the south of an outcrop of relatively highly radioactive black shale.

Special attention should be directed to the general range of external environmental radiation of 8 to 12 microrontgens/hour, and the fact that the higher readings are primarily associated with igneous bedrock areas. Although possibly of significance only in the matter of relative values, the 50 percent increase in the level of the higher radiation figure over the lower is similar to the difference between the malformation rates of 12.9 and 17.5 found in Table 4. These latter rates reflect the differences found between rural areas classified as probably not containing relatively large quantities of materials with elevated radioactivity versus those containing more highly radioactive igneous materials.

The general absence of unusually high external environmental radiation levels in river valley and morainal areas is offset by the potential radiation exposures to man via ground water used for drinking purposes. Epidemiological justification for this consideration is found in Table 8 where higher rates in these areas are associated with consumers of ground water supplies in contrast to large surface supplies. These data suggest that an internal factor acquired through drinking water may play a more important role than an external agent.

The association of increased malformation rates with residence in areas containing materials with relatively high levels of radioactivity strongly suggests radiation as a primary etiological agent. However, another etiological agent which may be associated with radioactive materials, may be responsible for the differences noted. Such an agent, however, is presently unknown and no known etiological factor other than radiation has the same statistical association with the malformation differences which are recorded. This applies to rubella, medical radiation, socio-economic status, consanguinity and the many other factors investigated in this study. Until such time as the existence of an alternate agent can be elicited, it would appear desirable to consider radiation as a causal agent. If such a causal association can be confirmed, it would serve as the basis for establishing more realistic and reliable information and standards pertaining to the long range effects on man of low level, environmental, radiation than those which have been extrapolated from laboratory experimentation with *Drosophila* and mice. Such information would be of special value in evaluating the hazards of environmental contamination by radioactive wastes and of fallout materials. Extensive additional radiological measurements will be required, however, before accurate estimates of these possible relationships can be made.

#### SUMMARY

1. A tabulation was made of all congenital malformations recorded for children born during 1948-1955 in New York State, exclusive of New York City.



Birth certificates, or certificates of death of children under five years of age, were used as sources of information. There were 16,369 malformations among 1,242,744 live births, an incidence of 13.2 per 1,000 live births. For the rural area the rate was 13.5. Rates of 20.0 or higher occurred in 186 out of a total of 942 townships. Contiguous groupings of these high rate townships occurred primarily in the Adirondack Mountains, Hudson Highlands and Allegheny Plateau portions of the State.

2. An independent compilation was made of all available geological data pertaining to deposits of materials with relatively high levels of radioactivity. These data were used to classify all townships as to the probable or unlikely presence of extensive quantities of natural materials with relatively high levels of radioactivity. The malformation rate for all rural areas classified as "probable" was 15.8 per 1,000 live births. For "unlikely" rural areas the rate was 12.9. The most highly radioactive materials in New York State are found in areas with outcrops of igneous rocks. These areas had the highest malformation rate, 17.5. Areas with extensive deposits of glacial materials had a rate of 15.4. These included river valleys in the Allegheny Plateau and glacial moraine areas. Areas with less extensive glacial deposits had a lower rate.

3. Birth record data pertaining to occupation of father were used to evaluate the relationship between malformation rates, presence of radioactive materials and socio-economic status. The neonatal mortality rate from malformations was inversely related to socio-economic status as indicated by occupation of father. However, there was no relationship between socio-economic status and the presence of radioactive materials. In "probable" radioactive material areas, malformation rates were higher than in "unlikely" areas for all but one occupational group.

4. Data pertaining to source of public water supply were used to evaluate the relationship between malformation rates, presence of radioactive materials, and drinking water from wells and springs as contrasted with large surface supplies

(lakes and rivers). In areas of "probable" radioactive materials, the malformation rate was highest, 16.9, in communities deriving their water supplies from wells and springs, and lowest, 12.4, in those utilizing surface waters. In the "unlikely" areas, the corresponding rates were 12.9 and 11.9.

5. Groups of contiguous townships with relatively high and relatively low malformation rates were selected for special epidemiological field study. Of the 55 high rate townships selected, 40 had been independently classified as "probable" areas, while of the 108 low rate townships, only 21 had been so classified. There were no differences between the high and low rate areas in the distribution of births by age of mother, age of father, number of previous children born to mother, or occupation of father. There were also no differences in infant mortality after the first month, or in the stillbirth rate. Possible biases associated with different reporting practices by hospitals, sampling variation in the selection of field study areas, and general under-reporting of malformations were investigated and could not account for the difference in rates between the high and low rate townships. There was no association between the incidence of rubella and malformations in any of the townships. Extensive family interview data revealed that medical radiation, infectious diseases during the first trimester of pregnancy and other potential etiological factors were not responsible for the malformation rate differences noted.

6. Field measurements of external environmental radiation levels were found to lie mainly in the interval of 8 to 12 microroentgens/hour with appreciable departures from this range at points adjacent to exposed minerals having an elevated radioactive content. These levels represent a range of from 2.1 to 3.2 roentgens per thirty-year period. Preliminary screening measurements of radium 226 for a limited number of water supplies revealed one highly radioactive supply from an igneous rock outcrop area, which contained  $29.0 \times 10^{-16}$  grams per ml. This level is in contrast to a general range of from 0.0 to  $1.7 \times 10^{-16}$  grams of radium per ml found in public water supplies. (14)

#### ACKNOWLEDGEMENTS

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Table 1

Births Recorded In New York State, Exclusive Of New York City, To Residents Of That Area  
and The Incidence Of Congenital Malformations Among Them, As Reported On The Birth  
Certificates Or On The Certificates Of Death Under 5 Years Of Age, 1948-1955

| Year    | Live Births | Birth Certificate | Number With Malformations Reported By |           | Birth or Death Certificate | Rate per 1,000 Live Births    |                                        |
|---------|-------------|-------------------|---------------------------------------|-----------|----------------------------|-------------------------------|----------------------------------------|
|         |             |                   | Death Certificate Only                |           |                            | Reported on Birth Certificate | Reported on Birth or Death Certificate |
|         |             |                   | Under 1 Year                          | 1-4 Years |                            |                               |                                        |
| 1948    | 141,098     | 1,481             | 401                                   | 74        | 1,956                      | 10.5                          | 13.9                                   |
| 1949    | 142,044     | 1,537             | 331                                   | 49        | 1,917                      | 10.8                          | 13.5                                   |
| 1950    | 143,163     | 1,475             | 325                                   | 40        | 1,840                      | 10.3                          | 12.9                                   |
| 1951    | 151,773     | 1,678             | 374                                   | 51        | 2,103                      | 11.1                          | 13.9                                   |
| 1952    | 159,760     | 1,760             | 349                                   | 42        | 2,151                      | 11.0                          | 13.5                                   |
| 1953    | 161,154     | 1,751             | 355                                   | 36        | 2,142                      | 10.9                          | 13.3                                   |
| 1954    | 168,822     | 1,796             | 330                                   | 15        | 2,141                      | 10.6                          | 12.7                                   |
| 1955    | 174,930     | 1,770             | 349                                   | -         | 2,119                      | 10.1                          | 12.1                                   |
| 1948-55 | 1,242,744   | 13,248            | 2,814                                 | 307       | 16,369                     | 10.7                          | 13.2                                   |

Table 2

Malformations Reported On The Birth Certificates Or On The Certificates  
Of Death Under 5 Years Of Age, According To Type Of Malformation:  
New York State, Exclusive Of New York City, 1948-1955

| Type of Malformation                | Total  | Malformation Reported On Birth Certificate |                           |              | Malformation Reported on Death Certificate Only |
|-------------------------------------|--------|--------------------------------------------|---------------------------|--------------|-------------------------------------------------|
|                                     |        | Not Known To Have Died                     | Died from:                |              |                                                 |
|                                     |        |                                            | Malformation <sup>a</sup> | Other Causes |                                                 |
| All malformations                   | 16,369 | 9,465                                      | 2,725                     | 1,058        | 3,121                                           |
| Central nervous system              | 2,595  | 578                                        | 1,459                     | 142          | 416                                             |
| Monstrosity                         | 476    | 31                                         | 356                       | 33           | 56                                              |
| Spina bifida and meningocele        | 1,223  | 379                                        | 703                       | 61           | 80                                              |
| Hydrocephalus                       | 631    | 66                                         | 343                       | 26           | 196                                             |
| Other                               | 265    | 102                                        | 57                        | 22           | 84                                              |
| Circulatory system                  | 2,715  | 194                                        | 617                       | 80           | 1,824                                           |
| Hard lip, cleft palate              | 1,414  | 1,267                                      | 41                        | 102          | 4                                               |
| Digestive system                    | 1,072  | 195                                        | 237                       | 53           | 587                                             |
| Genito-urinary system               | 1,270  | 1,037                                      | 102                       | 41           | 90                                              |
| Skeletal system                     | 2,276  | 2,131                                      | 5                         | 136          | 4                                               |
| Bones and joints                    | 1,461  | 1,276                                      | 41                        | 123          | 21                                              |
| Mongolian                           | 392    | 257                                        | 19                        | 78           | 38                                              |
| Other and unspecified malformations | 3,174  | 2,530                                      | 204                       | 303          | 137                                             |

<sup>a</sup> When cause of death was a malformation different from the malformation stated on birth certificate, case was allocated to malformation given as cause of death.

Table 3

Natural Occurrence Of Radioactive Elements

|                  | Re <sup>226</sup><br>-12<br>(10 gm/gm) | Th <sup>232</sup><br>-6<br>(10 gm/gm) | U <sup>238</sup><br>-6<br>(10 gm/gm) |
|------------------|----------------------------------------|---------------------------------------|--------------------------------------|
| Granite rock     | 1.6-4.7                                | 8-33                                  | 3.5                                  |
| Sedimentary rock | 0.3-1.0                                | 1-5                                   | 0.1-1.0                              |

Table 4

Malformation Rates Per 1,000 Resident Live Births\* In Areas Classified As To Probable or Unlikely Presence Of Extensive Quantities Of Materials With Relatively High Concentrations Of The Radioactive Elements: New York State, Exclusive of New York City, 1948-1955

| Presence of Extensive Quantities of Radioactive Materials                    | Total     |                      |      | Urban†  |                      |      | Rural   |                      |      |
|------------------------------------------------------------------------------|-----------|----------------------|------|---------|----------------------|------|---------|----------------------|------|
|                                                                              | Births    | Malformations Number | Rate | Births  | Malformations Number | Rate | Births  | Malformations Number | Rate |
| Total                                                                        | 1,242,744 | 16,369               | 13.2 | 690,506 | 8,925                | 12.9 | 552,238 | 7,444                | 13.5 |
| "Probable"                                                                   | 191,003   | 2,893                | 15.1 | 76,670  | 1,084                | 14.1 | 114,333 | 1,809                | 15.8 |
| Igneous bedrock areas, except those covered with water-laid glacial deposits | 27,521    | 462                  | 16.8 | 4,298   | 56                   | 13.0 | 23,223  | 406                  | 17.5 |
| River valleys in the Allegheny Plateau, and/or drift border areas            | 163,482   | 2,431                | 14.9 | 72,372  | 1,028                | 14.2 | 91,110  | 1,403                | 15.4 |
| "Unlikely"                                                                   | 1,051,741 | 13,476               | 12.8 | 613,836 | 7,841                | 12.8 | 437,905 | 5,635                | 12.9 |

\* Exclusive of births to residents recorded in New York City and other States.

† Incorporated places having a population of 2500 or more at the 1950 Census.

Table 5

Malformation Rates Per 1,000 Resident Live Births, 1948-1955, By Type of Malformation in Rural Areas of New York State Classified As To Probable or Unlikely Presence Of Extensive Quantities Of Materials With Relatively High Concentrations Of The Radioactive Elements

| Malformation Classification     | "Probable" Areas |      | "Unlikely" Areas |      |
|---------------------------------|------------------|------|------------------|------|
|                                 | Malformation     | Rate | Malformation     | Rate |
| All Malformations               | 1,809            | 15.8 | 5,635            | 12.9 |
| Central nervous system          | 254              | 2.2  | 857              | 2.0  |
| Circulatory system              | 299              | 2.6  | 939              | 2.3  |
| Mouth lip, cleft palate         | 181              | 1.6  | 529              | 1.2  |
| Digestive system                | 122              | 1.1  | 384              | 0.9  |
| Genito-urinary system           | 150              | 1.3  | 440              | 1.0  |
| Skeletal system (club foot)     | 264              | 2.3  | 779              | 1.8  |
| Bones and joints                | 148              | 1.3  | 466              | 1.1  |
| Other unspecified malformations | 356              | 3.1  | 1,104            | 2.5  |
| Mongolian                       | 35               | 0.3  | 137              | 0.3  |

Table 6

Regional Malformation Rates Per 1,000 Resident Live Births, By Probable or Unlikely Presence Of Extensive Quantities Of Materials With Relatively High Concentrations Of The Radioactive Elements: Rural Area Of New York State, 1948-1955

| Region                            | "Probable" Areas |                   | "Unlikely" Areas |                   |
|-----------------------------------|------------------|-------------------|------------------|-------------------|
|                                   | Births           | Malformation Rate | Births           | Malformation Rate |
| Total Rural Area                  | 114,333          | 15.8              | 437,905          | 12.9              |
| Adirondack Highlands              | 18,613           | 17.6              | 37,018           | 12.1              |
| Catskill-Pocahontas Highlands     | 10,895           | 14.2              | 11,430           | 14.0              |
| Northern Allegheny Plateau        | 42,981           | 16.1              | 27,682           | 14.6              |
| Northern Allegheny Plateau Border | 16,989           | 15.3              | 11,020           | 13.7              |
| Exile-Ontario-Johns Peak Plateau  | 19,136           | 14.6              | 169,103          | 12.1              |
| Hudson Valley and Long Island     | 5,719            | 15.4              | 185,652          | 13.2              |

Table 7

Malformation Data By Occupation Of Father

| de<br>s. | Occupation of Father                          | Death Rate<br>from<br>Malformations*<br>Upstate Area | Rural Area of 20 Non-metropolitan Counties, 1952 |                         |      |                  |                              |
|----------|-----------------------------------------------|------------------------------------------------------|--------------------------------------------------|-------------------------|------|------------------|------------------------------|
|          |                                               |                                                      | "Probable" Areas                                 |                         |      | "Unlikely" Areas |                              |
|          |                                               |                                                      | Births                                           | Malformations<br>Number | Rate | Births           | Malformations<br>Number Rate |
|          | Total                                         | 2.86                                                 | 7,689                                            | 126                     | 16.4 | 6,671            | 89 13.3                      |
| 2        | Professional, managers and officials.         | 2.60                                                 | 1,275                                            | 24                      | 18.8 | 791              | 12 15.2                      |
| 4,5      | Clerical and sales personnel, skilled workers | 2.75                                                 | 2,090                                            | 30                      | 14.4 | 1,747            | 21 12.0                      |
|          | Semi-skilled workers                          | 2.75                                                 | 1,659                                            | 26                      | 15.7 | 1,290            | 16 12.4                      |
| 9,X      | Service workers, laborers, and not reported   | 3.59                                                 | 1,553                                            | 22                      | 14.2 | 1,396            | 22 15.8                      |
| ?        | Farmers and farm laborers                     | 3.15                                                 | 1,112                                            | 24                      | 21.6 | 1,447            | 18 12.4                      |

Neonatal mortality (under 28 weeks) per 1,000 single white live births recorded Upstate to residents of that area, 1950-1952.

Table 8  
Malformation Rates Per 1,000 Resident Live Births, According To Source Of Public Water Supply and The Probable or Unlikely Presence Of Extensive Quantities Of Radioactive Materials: Incorporated Places Under 10,000 Population, New York State, 1946-1955

| Source of Public Water Supply   | "Probable" Areas |                      |      | "Unlikely" Areas |                      |      |
|---------------------------------|------------------|----------------------|------|------------------|----------------------|------|
|                                 | Births           | Malformations Number | Rate | Births           | Malformations Number | Rate |
| Total                           | 90,333           | 732                  | 12.5 | 160,742          | 1,936                | 12.0 |
| Wells and springs               | 15,307           | 239                  | 16.9 | 60,894           | 703                  | 12.9 |
| Large surface (lakes, rivers)   | 11,195           | 139                  | 12.4 | 31,275           | 371                  | 11.9 |
| Small surface (creeks, streams) | 11,213           | 149                  | 13.3 | 24,008           | 281                  | 12.7 |
| Mixed                           | 12,648           | 169                  | 14.7 | 34,565           | 472                  | 13.8 |

Table 9

Malformation Rates Per 1,000 Resident Live Births, In Areas Selected For Field Investigation Classified According To Type Of Unconsolidated Glacial Material: 1944-1955

| Type of Glacial Material                              | Total  |                      |      | Ice Laid |                      |      | Water Laid |                      |      |
|-------------------------------------------------------|--------|----------------------|------|----------|----------------------|------|------------|----------------------|------|
|                                                       | Births | Malformations Number | Rate | Births   | Malformations Number | Rate | Births     | Malformations Number | Rate |
| Total                                                 | 88,810 | 1,093                | 12.3 | 74,054   | 959                  | 13.0 | 14,756     | 134                  | 9.1  |
| Igneous                                               | 12,625 | 234                  | 18.5 | 11,254   | 219                  | 19.5 | 1,371      | 15                   | 10.9 |
| Mixed igneous*                                        | 13,516 | 187                  | 13.8 | 9,831    | 146                  | 14.9 | 3,685      | 41                   | 11.1 |
| Mixed shale†                                          |        |                      |      |          |                      |      |            |                      |      |
| "Extensive" quantities (areal distribution and depth) | 17,234 | 246                  | 14.3 | 17,234   | 246                  | 14.3 | -          | -                    | -    |
| "Limited" quantities‡                                 | 27,387 | 281                  | 10.3 | 26,868   | 278                  | 10.3 | 519        | 3                    | 5.8  |
| Shale                                                 | 19,048 | 145                  | 8.0  | 8,867    | 70                   | 7.9  | 9,181      | 75                   | 8.2  |

Igneous glacial material in which there are quantities of limestone, sandstone and similar sedimentary debris included.

Deposits associated with the alternating shale, sandstone, and siltstone beds of the upper Devonian of southwestern and south-central New York.

Table 10

Incidence Of Malformations, Stillbirths, and Abortions Among Siblings Of Index Cases and Controls

|                                                              | Index Cases With Malformation |                 |                | Index Cases Without Malformation |                 |                |
|--------------------------------------------------------------|-------------------------------|-----------------|----------------|----------------------------------|-----------------|----------------|
|                                                              | Total                         | High Rate Areas | Low Rate Areas | Total                            | High Rate Areas | Low Rate Areas |
| families interviewed                                         | 411                           | 203             | 208            | 425                              | 211             | 214            |
| live born siblings                                           | 1,207                         | 650             | 557            | 1,189                            | 631             | 558            |
| with malformations                                           | 71                            | 37              | 34             | 51                               | 36              | 15             |
| Rate per 1,000                                               | 58.8                          | 56.9            | 61.0           | 42.9                             | 57.1            | 26.9           |
| With mongolism, epilepsy, cerebral palsy, mental retardation | 7                             | 5               | 2              | 10                               | 7               | 3              |
| Rate per 1,000                                               | 5.8                           | 7.7             | 3.6            | 8.4                              | 11.1            | 5.4            |
| stillbirths                                                  | 43                            | 25              | 18             | 30                               | 20              | 10             |
| abortions                                                    | 125                           | 57              | 68             | 149                              | 75              | 74             |
| total stillbirths and abortions                              | 168                           | 82              | 86             | 179                              | 95              | 84             |
| Rate per 1,000 total sibling pregnancies                     | 122.2                         | 112.0           | 133.7          | 130.5                            | 130.9           | 130.3          |

UNIVERSITY OF ARIZONA,  
INSTITUTE OF ATMOSPHERIC PHYSICS,  
Tucson, Ariz., July 1, 1959.

Mr. JAMES RAMEY,  
Executive Director, Joint Committee on Atomic Energy,  
U.S. Senate, Washington, D.C.

DEAR MR. RAMEY: Thank you very much for sending me, at Senator Goldwater's request, copies of the 1958 hearings of the Hollifield Subcommittee on Radiation Effects. Thank you also for placing my name on the distribution list for the forthcoming publication of the 1959 hearings, which will also be of great interest to me.

I have just completed some statistical analyses of a recently published report that has, I believe, extremely strong bearing on the entire subject of this year's hearings. I am enclosing a copy of that analysis and I should like to see it included in the record of the 1959 hearings. I understand that the record is not yet closed.

This article, which should be footnoted as "Submitted for publication in the Bulletin of the Atomic Scientists," concerns interpretation of results of a study of relation of incidence of congenital malformation in New York State to radioactivity of the underlying rocks and water-bearing strata. As my article shows, the study reveals highly significant excesses in malformation rates in those parts of New York where the natural background of radioactivity is above normal. The study shows that farm families are particularly vulnerable in this respect.

I believe that this material warrants inclusion in the record of the Hollifield hearings since it constitutes evidence bearing on and contrary to the fifth and sixth items in the AEC General Advisory Committee's recent statement on fallout dangers. Contrary to the implications of that statement, there does now appear to be evidence that where people have been living with above-normal background radiation, their children have suffered increased probability of congenital malformation.

I hope, then, that my submitted material can be included in the hearings of the 1959 Hollifield subcommittee.

Thank you.

Respectfully yours,

J. E. McDONALD, Senior Physicist.

## A STUDY IN GENETIC DAMAGE

James E. McDonald

(Submitted for publication in the Bulletin of the Atomic Scientists)

The mutagenetic effects appearing within population groups subjected to sustained low-intensity radiation fields such as may be produced by radioactive fallout are only vaguely understood due to present ignorance of even such fundamental points as the ratio of induced to spontaneous mutations in humans. Appeals to the most qualitative and unscientific of human experience such as are to be found in the May, 1959 statement of the AEC General Advisory Committee<sup>1/</sup> serve to document our pitiful ignorance in this vital subject-area.

In view of present ignorance concerning the population-genetical effects of low-level irradiation, it is most gratifying to learn of recent completion of an extensive study that seems to provide, for the first time, some convincing biostatistical measures of genetic damage from natural background radiations. This study<sup>2/</sup>, which I shall refer to as the "New York study" for brevity, should be studied in full by all who can do so. Here, I want to give a brief summary of its methods and results for readers who may not have access to the medical journal in which it has been reported. I shall, in addition, discuss a number of ways in which I have tried to extend certain parts of the analysis of the New York study through use of statistical significance tests.

In the New York study one finds, I believe, important new evidence that where "we've been living with this stuff for years", we've been paying the genetic price -- even though we haven't been aware of it.

1/ See text published in Science, 129 (1959), p. 1413, especially items 5 and 6 of this statement.

2/ J. T. Gentry, E. Parkhurst, and G. V. Bulin, Jr., "An Epidemiological Study of Congenital Malformations in New York State", Am.J.Public Health, 49 (1959), p. 497.

The New York Study

The study had a curious origin: The director of the Syracuse University Speech and Hearing Center, noting what seemed to him an "unusually large number of cleft palate patients" who were coming to the Center from a single county in northern New York, pointed out this observation to Dr. J. T. Gentry, a regional director of the New York State Department of Health. From initial study of vital statistics for this county Gentry found anomalously high incidence of not just cleft palate but of several other types of congenital malformations in this county; and, still more suspicious, this was peculiar to a number of contiguous townships within that county. With the aid of a statistician and a geologist, Gentry proceeded from these initial clues to an intensive study of distribution and etiology of congenital malformation throughout New York state (exclusive of New York City itself). The findings bear on the controversial fallout problem with a force not to be found in radiobiological studies on mice, monkeys, or amoebae.

Very briefly, what Gentry, Parkhurst, and Bulin did in the New York study was the following: First they analysed medical statistics for the period 1948-55 to determine the statewide distribution of the frequencies of occurrence of all types of congenital malformations. Then they investigated various conceivable explanations for the non-random geographic distribution exhibited by these frequencies. The only explanation their results seemed finally to support was the explanation that more babies were being born with malformations in the areas of the state where slightly higher than average radioactivity is present because of surface occurrence of granitic rocks or black shale or because of drinking-water supplies derived from radioactivity-rich groundwater strata.



Data from one and a quarter million birth (or baby-death) certificates were initially examined to secure the basic facts. In this total sample, they found that about 16,000 individuals had been born with some kind of malformation, implying an overall mean malformation-rate of 13.2 per thousand births. Defects in the central nervous system or circulatory system accounted for about a third of these, with skeletal types next most frequent. Hare lip and cleft palate accounted for only a tenth of the total (ironical, in view of the origin of the study), with digestive tract and genitourinary system defects and a small percentage of cases of Mongolism completing the list.

In the course of the investigation, a program of comprehensive family interviews by public health nurses was set up in field areas scattered throughout New York state. This program established the fact that there exists no significant correlation between malformation rates and factors such as socio-economic status, national stock, consanguinity, dietary habits, or family medical history. Special attention was paid to incidence of rubella (German measles) in families with a malformation history, but no significant relation between areawise differences in incidence of rubella and areawise differences in incidence of congenital malformations was found. The overall result of the study was the conclusion that the critical factor could scarcely be any other than soil- or rock-radioactivity anomalies. Only this factor showed uniformly strong degree of association with observed variations in malformation rates.

In order to classify a given area (the township was the basic classification unit in the New York study) as "probable" or "unlikely" with respect to having above-normal radiation dosage rates, the investigators evolved a scheme based on several types of geological-

survey data. A township fell into their "probable" category if it satisfied any one or more of the following requirements: 1) It contained well-distributed outcrops of igneous rocks or of black shales, both of which are relatively rich in the radionuclides K-40, Th-232, Ra-226, and U-238; 2) or the township lay in a river valley in the Allegheny Plateau of the southern half of the state, since earlier radiometric surveys had indicated that such valleys often contain detrital materials capable of producing above-normal activity in water supplies; 3) or the township included terminal or recessional moraines lying less than 25 miles south of outcrops of igneous rocks or black shales so that glacial transport might be expected to have brought in significant radioactivity in the glacial debris. In all cases, a township had to have half or more of its entire area within the "probable" category in order for that township to be termed "probable".

#### Some Findings

If lithology of surface outcrops and soil materials were an underlying factor in the etiology of the malformations, this factor might, the investigators reasoned, be expected to produce the most marked differences in those areas where residents are more exposed to natural materials, namely in the rural areas. The analysis confirmed this.

Thus, for just the rural areas (552,238 live births, including 7,444 malformation cases in the 8-year period), the overall mean malformation rate per thousand births was found to be 13.5 (as contrasted with the urban rate of 12.9). In the "probable" rural areas this rate rose to 15.8; in the "unlikely" rural areas it fell to 12.9. When the investigators separated from all the "probable" rural areas

just those overlying igneous bedrock, the resulting subsample exhibited a rate of 17.5 (406 malformations in 23,223 births for the subsample). Thus if we contrast igneous-bedrock "probable" areas vs. all "unlikely" areas in rural New York, we find the former displaying an incidence of congenital malformations that is 36 per cent higher than the latter, a rather startling result.

As one examines the New York study, he is repeatedly impressed with the way in which the differences in malformation rates between "probable" and "unlikely" areas manifested themselves no matter how the data were subdivided and reanalysed. For example, the findings showed that out of nine subtypes of malformations, the "probable" areas exhibited higher rates than the "unlikely" areas in eight subtypes, while in the ninth (Mongolism) the two rates were identical. Similarly, the study revealed that on subdividing the entire state into six subregions and tabulating comparative rural-area malformation rates for "probable" and "unlikely" areas, there appeared uniformly higher incidences in the "probable" sections of each one of the six subregions. It is worth note that the largest difference appeared in the "Adirondacks Highlands" subregion, where "probable" areas averaged 17.8 while "unlikely" areas averaged 12.1 malformations per thousand births. Thus the "probable" areas ran some 47 per cent higher in malformation incidence than the "unlikely" areas in the Adirondacks. This maximal subregional difference stands in striking agreement with the investigators' map of distribution of types of rock outcrops in the state, for the Adirondacks subregion is almost coextensive with New York's igneous-bedrock region.

Proceeding on still another tack, the investigators examined the occupation of the fathers of children born in rural areas in 20 non-

metropolitan counties in just the single year 1952 (total sample, about 14,000 births). By far the strongest father-occupational contrast in malformation rates between "probable" and "unlikely" areas occurred for children born of "farmers or farm laborers". The size of this particular subsample was small (2,559 births for the combined categories), but the difference cannot easily be put aside, for it is very large -- 21.6 in the "probable" areas as contrasted with only 12.4 in the "unlikely" areas.

#### Statistical Significance?

It is very much in order to ask whether these and other interesting differences in malformation rates reported in the New York study might have arisen as a result of merely random sampling fluctuations. That is, we must ask, "Are these differences really statistically significant?"

With only a single exception, the authors of the New York study did not make significance estimates for the stated (but to me unclear) reason that the binomial distribution would yield too-low standard errors. However, noting that not only in the major subdivisions of their data but also in even their smallest subsamples the numbers of cases involved satisfy the usually accepted requirement<sup>2/</sup> for application of the standard test for the significance of the difference between two proportions (based on the normal distribution as the large-sample limit of both binomial and Poisson distributions), I have proceeded to use this test to assess the significance of the difference between pairs of malformation rates for all of the most important comparisons in the New York study. I shall summarize my results here

<sup>2/</sup> Particularly explicitly put in J. F. Kenney, "Mathematics of Statistics", Part Two, Van Nostrand (1942), p. 120.

to the extent that they shed further light on the main issues raised by the study<sup>4/</sup>.

First, it is of broadest interest with respect to the entire study to ask whether we can attach statistical significance (in the sense of rejection of the null hypothesis) to the reported difference in malformation rates between "probable" and "unlikely" rural areas as a whole, i.e., 15.8 and 12.9 per thousand births, respectively. The standard error for this difference is found to be 0.37 in units of malformations per thousand births, while the observed difference in rates was 2.9 per thousand, or 7.8 standard errors. Ordinary tables of the normal distribution do not extend to limits permitting one to read out an exact value of the probability of chance occurrence of so large a ratio of difference to standard error, but the tables show that it is well below  $10^{-10}$ . By contrast, it may be noted that it is conventional to describe as "statistically significant" a difference that is associated with a probability of 0.05 or less of having arisen solely from random sampling fluctuations. The primary reason that such an extremely high degree of statistical significance may be attributed to the 15.8 vs. 12.9 rate-difference is simply that it has been derived

<sup>4/</sup> Throughout the remainder of the discussion, I refer only to significance tests of the null hypothesis that the observed differences in malformation rates arose simply by chance in sampling from hypothetical parent populations of zero mean rate-difference. Because the assignment to "probable" or to "unlikely" areas implies a prediction of the sign of the difference in rates, the one-tailed test will always be appropriate. The reader who may seek precise identification of the test used here will find it, for example, in L. Cohen, "Statistical Methods for Social Scientists", Prentice-Hall (1955), p. 118.

from an extremely large sample, a sample comprising over half a million babies. (For the entire New York study sample of 1,242,744 births, the "probable" vs. "unlikely" difference, 15.1 minus 12.8, equals 8.2 standard errors! The urban areas, i.e. incorporated places of over 2,500 population, with a total of 690,000 births, gave rates of 14.1 vs. 12.8, the difference being significant at the 0.001 level.)

This very impressive significance level is not seriously altered even when one subdivides the "probable" areas into two smaller subsamples that are of present interest: Comparing just those "probable" areas overlying igneous bedrock with all "unlikely" areas gives rates of 17.5 and 12.9, respectively, and for this comparison one computes a level of significance of about  $10^{-7}$ . The null hypothesis is again rendered almost inconceivable. The other two of the three categories of "probable" areas when lumped together (river valleys in Allegheny Plateau plus glacial drift areas near active outcrops) and set off against the set of all "unlikely" areas yield comparative rates of 15.4 and 12.9, respectively; and, due to larger sample size, this smaller difference also proves to be significant at the  $10^{-7}$  level.

It was pointed out earlier that of nine subtypes of congenital malformations, all but one (Mongolism) exhibited higher incidence in "probable" than in "unlikely" rural areas. This near-uniformity in the sign of the difference is itself a qualitative indicator of significance. I find that almost all of the differences are, in addition, quantitatively significant, and this despite the relatively small rate-differences that arise within subtypes. For example, for the subtype of circulatory system malformations (most frequently reported subtype in the New York study) the difference between the rates of 2.61 and 2.15 per thousand proves to be significant at the 0.002 level.

The subtype made up jointly of hare lip and cleft palate, the subtype that might be said to have provided the tipoff to the entire study, gave overall rates of 1.58 and 1.21 for which the difference is significant at the 0.001 level. Other subtype significance levels for rejection of the null hypotheses are as follows: Central nervous system 0.04; skeletal system (club foot) 0.0002; digestive system 0.008; genitourinary system 0.003; bones and joints 0.02; and other unspecified malformations 0.0003. Aside, then, from Mongolism, all eight subtypes exhibited statistically significant rate-differences.

On testing the null hypotheses concerning comparisons within the father-occupational analysis, I found that four out of five were non-significant (all four significance levels in question lay above 0.25). This may be due partly to the small sample size, since this analysis was based on only a 20-county sample for only one year (1952); but I believe, as I shall elaborate below, that it may also reveal real differences in exposure rates. Unlike the other four subclasses, in the occupational subclass of "farmers and farm laborers", the very striking rate difference of 21.6 for families in the "probable" areas vs. 12.4 for families in the "unlikely" areas proved significant at the 0.03 level. Tending further to support the view that farm families comprise an unusually exposed group, I found that comparing farmers against all other occupations within just the "probable" category alone (21.6 vs. 15.5) gave borderline significance at the 0.07 level. And, still compatible with the basic finding of the study, this last kind of comparison, when made within just the "unlikely" category gave very different results -- the rate for children of farmers is then found to be 12.4 while that for children of fathers in all other occupations is actually higher, 13.6, though the negative difference is non-

significant (0.35 level). It would seem that farm families may be carrying a disproportionate share of the genetic burden that shows up in the various rate-differences throughout the New York study. Here a redesign of the basic analysis might yield even more startling differences between, say, geographical subregions, or between malformation subtypes, if broken down systematically into farm versus non-farm families. But the study, as it now stands, already goes very far toward pointing out the farm baby as singularly unfortunate: Farm babies in "probable" areas are over 70 per cent more likely to be born with malformations than are farm babies in "unlikely" areas, judging from this sample, with the odds being over thirty to one that this excess is no mere play of chance. Furthermore, farm babies in "probable" areas are about 40 per cent more likely to be born with malformations than are all other babies in just these same "probable" areas, the odds being about fourteen to one that chance alone could yield so large a rate-difference. This latter finding deserves follow-up study employing much larger samples to assess its significance more adequately, for it is this 40 per cent excess that particularly bears on the relative exposure hazard for farm families.

Another part of the New York study wherein significance-testing turns up clues to potential refinements of analysis at the same time that it confirms the suspicion that the natural background dosage is causing significant numbers of deleterious mutations is the portion of the study dealing with the role played by drinking-water supplies. Without elaborating hydrologic details, it should be evident that for a given concentration of soil and rock radioactivity, human dosage rates ought to run higher for communities where drinking water comes from wells and springs than for communities deriving their water from large lakes or rivers (minimal contact with bedrock and soil minerals). To test this and related questions, Gentry and

co-workers examined malformation-rate data for 555 incorporated New York communities of under 10,000 population served by public water supplies (total sample about 201,000 births).

Comparing malformation rates just within the "probable" category alone, we find that for communities depending on wells or springs the rate is 16.9 while for communities also in "probable" areas but deriving their water supplies from lakes or rivers the rate is only 12.4. This difference is significant at about the 0.001 level. This same type of comparison made entirely within "unlikely" areas gives 12.9 for communities using well- or spring-water and 11.9 for communities using lake- or river-water; and this much smaller rate-difference yields, by contrast with that for "probable" areas, a 0.10 significance level. Briefly, malformation rates run significantly higher among populations drinking well- or spring-water if the wells or springs lie in areas characterized by above-normal ground-radioactivity, but malformation rates are not significantly higher among populations drinking well- or spring-water in areas of generally low ground-radioactivity. Since these results are based on many tens of thousands of births scattered through many different New York communities, they would seem to constitute a meaningful rebuttal to the implied claims contained in the AEC General Advisory Committee's May, 1959, statement cited earlier here.

The same water-supply data can be reexamined in another way: Among all communities depending upon wells or springs, the malformation rate for "probable" areas, 16.9, differs from the rate for "unlikely" areas, 12.9, by an amount highly significant at the 0.0001 level. This comparison only strengthens our suspicions that the malformation rate-differences in question are significantly influenced by mutagenic effects of ingested radionuclides. But when we look at the same type of comparison for just the communities dependent upon

lakes or rivers, the small difference between the "probable" areas' 12.4 and the "unlikely" areas' 11.9 is not found to be significant (0.34 level). Considering these two intercomparisons solely from the viewpoint of dosage due to ingested water, both are reasonable; but considering the latter intercomparison more broadly, we are led to ask why we don't find a modest but at least significant difference between malformation rates for "probable" vs. "unlikely" areas here, too. Why, that is, doesn't terrain radioactivity alone yield a significantly higher malformation rate in these particular "probable" areas?

If a full answer can be given to this question it will be very valuable information; but without direct access to all original data, one cannot decide this important issue. Taken by itself, the last of the above significance tests would suggest that mere presence of rock- and soil-radioactivity in an area will not insure anomalously high malformation rates. Instead, this last comparison indicates that, for mutagenic effects to occur, potential parents must actually be drinking water that has had good opportunity to leach out and ultimately transport the mutagenic radionuclides into their bodies. Clearly, here is an important point to settle.

Finally, we may consider significance of rate-differences within geographical subregions. For the Adirondacks Highlands, with rates of 17.8 vs. 12.1, the odds are about a million to one against so large a difference arising solely by chance (significance level  $10^{-6}$ ). But, in strong contrast, the Catskills-Pocono Highlands subregion (14.2 vs. 14.0) gave a significance level of 0.13; so here we may not very safely reject the null hypothesis. In the Northern Allegheny Plateau subreg-

(16.1 vs. 14.6) the significance level of 0.06 was almost but not quite below the 0.05 limit.<sup>5/</sup> The Northwestern Allegheny Plateau Border rates were 15.3 vs. 13.7 with a significance level of 0.14; so here we may not quickly reject the null hypothesis, either. The Erie-Ontario-Mohawk Plain subregion, however, exhibited rates of 14.8 vs. 12.1, differing by an amount significant at the 0.001 level. Finally, the sixth subregion, Hudson Valley and Long Island, with rates of 15.4 and 13.2, gave significance at the 0.07 level, again a bit above the usual limit for rejection.

I believe that the heterogeneity of the subregions with respect to significance levels contains an important clue to possible methodological improvements, for the scheme of classification of areas as "probable" vs. "unlikely" systematically loses its sharpness with certain portions of the state of New York. Although only detailed study of the original geologic and biostatistical data would permit a final opinion, I suspect that the investigators' "river valley" criterion for "probable" areas may be weak. This could account for the less impressive significance levels noted above for the Catskills-Pocono Highlands and for the Northwestern Allegheny Plateau Border subregion.

<sup>5/</sup> Perhaps, for benefit of any readers unfamiliar with the rationale of significance testing, it should be emphasized that there is really no magic in using 0.05 as a rejection limit for null hypotheses. Statisticians have come to use this as a reasonably conservative requirement for run-of-the-mill problems. In a problem whose human import is as great as that of the genetic-damage problem, gain-loss-risk arguments should probably dictate a limit of rejection of our null hypotheses nearer 0.50 than 0.05. Put technically, we wish to avoid a Type II error here.

#### Exposure of Farm Laborers

Why should the difference in malformation rates between "probable" and "unlikely" areas be so very significant not only in the Adirondacks Highlands with their widespread outcrops of silicic granites known to have above-normal activity, but also in the Erie-Ontario-Mohawk Plain that is almost devoid of igneous outcrops and that has only sparsely exposed black shales? I believe careful consideration should be given the hypothesis that this latter significant difference arises through the interplay of two factors: First, the Erie-Ontario-Mohawk Plain contains a large fraction of the agricultural land in New York and, secondly, as emphasized above, there exists a noticeably greater tendency for malformation-births to occur in families of farmers and farm laborers than in families of any other occupational subclass.

Unable to secure actual rural-urban population figures for the New York counties in question to check the first factor, I have examined the less conclusive matter of per cent of land in cultivation. From a recent agricultural census<sup>6/</sup>, I found that 27 per cent of all land falls in the category of "cropland harvested" in the eleven counties lying entirely within the Erie-Ontario-Mohawk Plain subregion, with peak countywise percentages of about 40 per cent occurring in Orleans, Niagara, and Genesee counties. By way of rough comparison, I tallied the corresponding figures for the eight counties in the Adirondacks subregion for which the New York study maps indicated igneous bedrock to be present over about three-fourths of the county

<sup>6/</sup> Dept. Commerce, Bur. of Census, "1954 Census of Agriculture", Vol. 1, part 2, pp. 44-49.

and obtained the result that only 8 per cent of this land is in "cropland harvested". These figures may at least serve to support crudely the statement that the Erie-Ontario-Mohawk Plain subregion is relatively heavily farmed.

As to the above-normal exposure of farm families to background dosage, the malformation-rates have already spoken for themselves. As to the actual mechanism of this exposure, two quite different possibilities exist: We might argue that farm men and women are outdoors a great deal and that the men who actually do field-cultivation are particularly exposed to terrain radioactivity. This may, in fact, be the primary factor. However, as a second possibility, we may recall the fact that in the significance-testing of the rate-differences arising in the data-breakdown with respect to nature of drinking-water supplies it was noted that malformation rates were not significantly higher in "probable" areas than in "unlikely" areas so long as we drew the comparison entirely within communities deriving their water from lakes and rivers, whereas a highly significant difference arose for the same kind of comparison as soon as we compared communities dependent upon wells and springs. Now it seems entirely safe to assert that "farmers and farm laborers" and their wives must derive virtually all of their drinking water from wells or springs in upstate New York just as do farm families elsewhere. Hence it is a rather attractive hypothesis to suppose that the surprisingly high significance of the rate-difference between the "probable" vs. "unlikely" areas within the Erie-Ontario-Mohawk Plain results from the fact that, despite general scarcity there of highly radioactive rocks or soils, wherever these do occur (i.e., wherever a "probable" area does actually exist

within this subregion), there will probably be farmers living on and these farmers will be deriving their drinking water supplies from a well or spring that insures relatively high dosage for themselves and their wives. This speculation warrants careful check. In contrast to the above hypothesis that seems rather nicely to tie together a number of findings, farm-family malformation rates high due to actual terrain-exposure attending field cultivation badly need to know this. Any survivors of a major nuclear war probably be cultivating, for some years after such a war, fields contaminated to levels far exceeding any now existing in New York and these few survivors would be cultivating them with the primitive techniques guaranteeing very much greater body burden than is typical of today's tractor-borne farmer on the Mohawk. My suspicion, however, is that the water-supply hypothesis is the correct key to understanding the results for the Erie-Ontario-Mohawk Plain.

#### Why New York?

It is pertinent to ask whether there is something in the geology of New York that renders its "probable" areas unusually susceptible to in mutagenic radiations.

As a meaningful, though indirect, indicator of the widespread occurrence of surface deposits that must maintain local dosage rates at levels much more detrimental to the residents than does the radiation activity of New York's most active areas, one should consider the implications of the newly-developed technique of airborne radiometric surveying. Using the best large-volume crystal detectors and flying only a few hundred feet above terrain, this technique succeeds only when there exist surficial anomalies of radioactivity amounting to

about 20 ppm eU<sup>7/</sup>. Since "typical granite" constitutes a background with about 10-20 ppm eU, we can say that airborne surveying depends upon existence of positive excesses of about 100 per cent of normal granitic background. From limited radiometric data contained in the New York study one infers that the more active New York areas give dosage rates very close to "typical granites", and absence of major fissionable-material mining operations in New York tends to confirm this. Considering these points, then, we can say that airborne detection of the important radiometric anomaly fields near Grants, New Mexico, in the Wind River Basin and other Tertiary basins of Wyoming, in the Maybell-Lay district in northwestern Colorado, in the Edgmont district of South Dakota, and in numerous other parts of the western United States attests to the existence of many areas that must considerably exceed upstate New York with respect to intensity of mutagenic radiation fields.

Similarly, the black shales used as one of the criteria for the "probable" areas in the New York study are relatively common. Uraniferous shales and slates in Kentucky and Tennessee (Chattanooga shales), Ohio, and Michigan are cases in point.

Lastly, as a rather different means of showing that New York state is not at all likely to represent an extreme case, I have tabulated nationwide figures on infant deaths due to congenital

<sup>7/</sup> R. M. Moxham, "Geologic Evaluation of Airborne Radioactivity Survey Data", 2d U. N. Int. Conf. on the Peaceful Uses of At. En., Geneva, A/Conf.15/P/1907, (1958). The unit "ppm eU" represents "parts per million equivalent uranium".

malformations<sup>8/</sup>. A pilot-run showed the rates to be surprisingly stable between years, so I tallied only a single year's statistics (1955). Using 1955 Bureau of Census state-population estimates as a simple but adequate basis for normalization, I computed and ranked the incidence of infant mortality prior to age one year wherein death was attributable to any type of congenital malformation.

The most interesting single item of information so gleaned was the result that New York is nowhere near the top in infant death-rates due to congenital malformations: It is, in fact, thirty-ninth from the top among the states, with a rate of 88 deaths in 1955 per million total population. Highest on this list was New Mexico with 129 such deaths per million. The nationwide average was 95 per million. Lowest death rate due to malformations for 1955 was 73 per million total population in Arkansas.

Six of the seven highest states (New Mexico, South Dakota, Arizona, Kentucky, Colorado, and Michigan) are states with abundant granites or other surficial radioactivities, but whether this has real significance I cannot say. One must be careful to keep in mind that abundant sources of potential human dosage will not actually affect vital statistics significantly unless the sources occur in

<sup>8/</sup> In the New York study four-fifths of the malformation data came from direct tabulation from birth certificates, and only one-fifth from baby-death certificates. I found vital statistics published only for deaths due to malformations, and hence limited my tabulation to <sup>this</sup> just/less complete but accessible type of information. Reference: U. S. Dept. of Health, Ed. and Welfare, "Vital Statistics of the United States", (1955), Vol. 1, pp. 350-366.



areas of relatively high population density. Nevada, next to the lowest on my list, is a case in point: A map of areas aerial-radio-metrically surveyed by AEC flight groups<sup>9/</sup> shows that of the 13,000 square miles so surveyed in Nevada most of it is well away from that state's half-dozen communities of any appreciable size. Colorado's surveyed 11,000 square miles and New Mexico's surveyed 9,000 square miles do, on the other hand, overlap significantly those two states' areas of relatively high population density, and it may then be more than coincidence that these states rank very high with respect to infant deaths due to congenital malformations<sup>10/</sup>.

In all, it would appear that New York is by no means unusual with respect to its terrain radioactivity. There should be many areas

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9/ T. L. Boyle, "Low-level aerial radiometric surveying in the U.S.A.", 2d U. N. Int. Conf. on Peaceful Uses of At. En., Geneva, A/Conf.15/F/775, (1958).

10/ Still further evidence that moderate natural-background anomalies discernibly influence mutation rates may underly the fact that a puzzlingly high rate of premature births and of babies of subnormal weight has been reported for 11,000-ft.-high Lake County of Colorado. Cosmic ray flux would run about 50-60 mr/yr higher at such altitudes than at sea level, and AEC maps show that aerial radiometric surveys were run in an area overlapping the southeastern part of Lake County, so a local dosage rate upwards of 200 mr/yr seems entirely conceivable. See U.S. Dept. Health, Ed. and Welfare, "Public Health Reports", 70 (1955), p. 230, for data on Lake County natal anomalies, including thrice-normal incidence of premature births.

of the country within which replications of the New York study might be expected to reveal even larger malformation-rate differences than Gentry, Parkhurst, and Bulin have found in upstate New York.

#### Conclusions

The New York study seems to show, with an impressively high degree of statistical significance, that rather ordinary degrees of departure from average background dosage yield roughly proportional departures from average in the associated congenital malformation rates. Some of the most pertinent rate-differences are significant at the level of million-to-one odds that pure chance could not have produced such large differences as were observed. The basic reason for the high significance of results of the study is that it is very much a large-sample study. Its basic data (a million and a quarter births) were an order of magnitude more numerous than those used in the joint American-Japanese study of births to parents exposed at Hiroshima or Nagasaki, and rival the sample-sizes of even the Oak Ridge mice factories.

New York is not a state with any unusual abundance of surface radioactive materials. Geologic and radiometric-survey data would lead one to expect that many other regions within the United States must be characterized by local dosage rates well above those in the more active areas of New York. Biostatistical analyses should be carried out to check the prediction that deleterious mutations are, in such other regions, also significantly increasing the rate of births of malformed babies. That such a prediction is not rash is suggested by the fact that New York was found to rank thirty-ninth in 1955, among the forty-eight states with respect to infant death rate associated with congenital malformations: New York is no hotbed

of radioactivity as the states go.

Farm families exhibited the greatest differences (70 per cent excess, significant at the 0.05 level) with respect to frequency of malformed children in "probable" vs. "unlikely" areas of New York. This occupational hazard of relatively heavy exposure to radioactivity may explain the surprisingly high degree of statistical significance for the observed difference in malformation rates between "probable" and "unlikely" areas within the highly agriculturalized Erie-Ontario-Mohawk Plain subregion of New York. The most plausible explanation for the anomalous exposure of farm families in general seems to be that farmers derive drinking-water supplies from wells or springs. In groups that drink well- or spring-water in areas of above-average radioactivity, malformation-rates tend to run significantly above average, as the New York study shows.

In all, the chief significance of the New York study resides in the fact that it shows, with unprecedented cogency, that where "we've been living with this stuff for years" the genetic price has been paid in the currency of handicapped lives. There is urgent need to secure much more extensive quantitative data, in the New York area and in other areas, with respect to actual dosage rates due to ingested water or to terrain radioactivity. It would now appear that such data plus large-sample malformation-rate data can provide the desperately needed yardstick with which to measure the true dimensions of the population-genetical consequences of worldwide fallout due to nuclear weapons.

## APPENDIX G

## CARBON 14

RADIOACTIVE HAZARDS FROM CLEAN HYDROGEN BOMB AND  
FISSION ATOMIC BOMB EXPLOSIONS

by O. I. Leipunsky

(United Nations translation with minor corrections)

The author estimates the hazards to mankind of the long-lived radioactive substances dispersed throughout the world after the explosion of an ordinary (fission) bomb and a pure hydrogen (fusion) bomb. The pure hydrogen bomb considered in this article is of the deuterio-tritium variety.

He calculates the radiation doses to the gonads and bones, the corresponding number of children born suffering from hereditary diseases and the number of cases of leukemia (cancer of the blood). The active agents are C-14 and H-3, in the case of a hydrogen bomb, and Sr-90, Cs-137 and C-14 in the case of an ordinary bomb. The distribution of radioisotopes in nature and in the organism is taken into account. Cases involving surface hydrogen-bomb explosions are also discussed. The total energy of radioactive decay of the products of a deuterio-tritium bomb explosion is three times greater than in the case of an ordinary bomb. The radiation dose to the tissues and the number of persons affected throughout the whole period of radioisotope decay in the explosion of both types of bombs of energy equivalent to 10 megatons of TNT are approximately the same and are as follows (in round figures):

|                                                                | Deuterio-tritium<br>bomb | Ordinary bomb            |
|----------------------------------------------------------------|--------------------------|--------------------------|
| dose to the tissues                                            | $50,000 \times 10^{-6}r$ | $40,000 \times 10^{-6}r$ |
| dose to the bones                                              | $50,000 \times 10^{-6}r$ | $88,000 \times 10^{-6}r$ |
| number of mutants<br>(per $2.5 \times 10^9$ persons)           | 50,000                   | 40,000                   |
| number of cases of leukemia<br>(per $2.5 \times 10^9$ persons) | 15,000                   | 26,000                   |

Thus, as regards the amount of radiation damage it causes to mankind, a pure hydrogen (deuterio-tritium) bomb cannot be regarded as less dangerous than an ordinary bomb.

Every large atomic explosion causes damage not only in the area and at the time of the explosion, but throughout the world and for hundreds and thousands of years after the explosion.

The long-term effects of an atomic explosion are due to the radioactive substances which are formed during the explosion and are scattered fairly uniformly throughout the world.

The purpose of this paper is to evaluate the relative hazards of the explosion of an ordinary bomb, i.e., a fission bomb, and that of a pure hydrogen (deuterium-tritium) bomb, on the basis of the calculation of the radiation doses and the number of genetic damage caused by the radioactive products of these explosions. The study covers the effects of the radioisotopes scattered throughout the world, their effect in the area of the explosion is not considered.

## 1. Radioisotopes and physical data

### Quantitative criteria of the hazard

Preferred exposure to small doses of radiation is characteristic of the case under consideration. The most significant harmful effects (of those studied) of preferred exposure of this kind are the genetic consequences and the appearance of malignant neoplasms. A quantitative appraisal can be made with regard to the number of mutant births (i.e., the number of infants born with characteristics due to mutant genes) and of one type of malignant neoplasms, namely, leukemia (so-called cancer of the blood).

The number of mutant genes that appear as the result of irradiation may be determined by reference to the genetic equilibrium which has been established through the constant exposure of the human organism to natural radiation: the number of mutant genes eliminated through the death of mutants without offspring is equal to the number of new mutants formed by the effects of the radiation, the number of mutants being proportional to the radiation dose.

For geneticists it is an established fact that 2 per cent of all children are born with serious hereditary diseases, i.e., mutant genes appear in 2 per cent of all births (1). It is cautiously estimated that about 10 per cent of these cases are due to exposure to natural radiation at a rate of 0.18 r/year, or  $5.4 \times 10^{-2}$  r over a period of 30 years, i.e., the number of mutants produced by natural radiation is equal to  $2 \times 10^{-2} \times 10 \times 10^{-2} = 2$  per million of total births from one person. The coefficient of proportionality between the dose and the percentage of mutant births is:

$$\frac{2 \times 10^{-2}}{5.4} \sim 4 \times 10^{-4} \text{ mutants/birth} \times 1 \text{ r.}$$

In order to determine the number of mutants per person in this calculation, the resultant percentage of births must be multiplied by the number of births from one person throughout life, i.e., by  $3 \times 10^{-2}$  births/year  $\times$  30 years = 1 birth/person.\*

Thus the coefficient of proportionality between the number of mutants and the dose received by the person is:

$$B_0 = 4 \times 10^{-4} \text{ proportion of mutants/births} \times 1 \text{ r} \times 1 \text{ birth per person} = 4 \times 10^{-4} \text{ mutants/person} \times 1 \text{ r.}$$

The number of mutants is equal to the product of the number of births  $B_0$  by the number of persons irradiated and the radiation dose to the genome.\*\*

Leukemia is induced particularly by irradiation of the bones. The probability of induction is proportional to the average radiation dose to all bones and is equal to  $2 \times 10^{-6}$  cases per year per person per 1 r (2). Thus a given radiation dose will induce the following number of leukemias, calculated per person:

\* It is assumed that the normal birthrate is 50 per 1000.

\*\* According to other and also reasonably acceptable figures, the proportion of mutants to the total number of births is 4 and not 2 per cent, and the proportion of mutations induced by the natural radiation background is 25 per cent; in this case the number of genes destroyed will be four times greater than the figure calculated in this paper.

$$N_1 = 2 \times 10^{-6} \frac{\text{cases}}{\text{year} \times \text{person} \times 1 \text{ r}} \times 60 \text{ years}$$

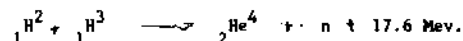
$$= 1.2 \times 10^{-4} \frac{\text{cases}}{\text{person} \times 1 \text{ r}}$$

The number of leukemias is equal to the product of  $N_1$ , the number of persons and the radiation dose to the bones.

Other possible harmful effects are not taken into account as quantitative criteria for their calculation are not available.

#### Basic physical data

The pure hydrogen bomb referred to is assumed to be a deuterio-tritium bomb, in which the following reaction takes place:



Ten single  ${}_1^2\text{H} + {}_1^3\text{H}$  reactions correspond to an energy release of 180 Mev., equivalent to the energy of one single fission. In a fusion explosion 10 neutrons are emitted per 180 Mev., as against 1.5 neutrons in a fission explosion. The neutrons emitted are captured by the nitrogen in the air to form C-14 by the reaction  $\text{N}^{14} (n, p)\text{C-14}$ . In a pure hydrogen bomb explosion allowance is made for C-14 in the amount of 10 atoms per 180 Mev. of energy and for residual H-3 in the amount of 1 atom per 180 Mev. of energy.

In a fission explosion, the radioactive products of significant importance are Sr-90 ( $4.6 \times 10^{-2}$  atoms per 180 Mev. of energy), Cs-137 ( $6 \times 10^{-2}$  atoms per 180 Mev.) and C-14 (1.5 atoms per 180 Mev.). In a fission explosion one-seventh as much C-14 is formed per unit of energy as in the case of a pure hydrogen-bomb explosion.

Table 1 gives the characteristics of an ordinary bomb and a pure hydrogen-bomb explosion equivalent in energy to the detonation of 10 mgt. of TNT\*

Table 2 shows the characteristics of the radioactive products of the explosion.

\* 10 mgt. of TNT = 10 megatons of trinitrotoluol (trotyl) =  $10^{13}$  large calories.

Table 1\*

Reaction products of a 10 megaton-equivalent explosion

|                                               | Ordinary atomic bomb explosion                                                                               | Pure hydrogen bomb explosion                                                                                 |
|-----------------------------------------------|--------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
| Number of fissions                            | $1.45 \times 10^{27}$                                                                                        | -                                                                                                            |
| Number of $\text{H}^2 + \text{H}^3$ reactions | -                                                                                                            | $1.45 \times 10^{28}$                                                                                        |
| Number of neutrons released                   | $2.2 \times 10^{27}$                                                                                         | $1.45 \times 10^{28}$                                                                                        |
| Amount and disintegration energy of Sr-90     | $6.7 \times 10^{25}$ atoms<br>$10^4$ g.<br>$1.45 \times 10^6$ curies<br>$6.7 \times 10^{25}$ Mev.            | -                                                                                                            |
| Amount and disintegration energy of Cs-137    | $8.7 \times 10^{25}$ atoms<br>$1.57 \times 10^6$ curies<br>$7.10^{25}$ Mev.                                  | -                                                                                                            |
| Amount and disintegration energy of C-14      | $2.2 \times 10^{27}$ atoms<br>$5.2 \times 10^4$ g.<br>$2.34 \times 10^5$ curies<br>$1.1 \times 10^{26}$ Mev. | $1.4 \times 10^{28}$ atoms<br>$8.5 \times 10^5$ g.<br>$1.49 \times 10^6$ curies<br>$7.5 \times 10^{26}$ Mev. |
| Amount and disintegration energy of H-3       | -                                                                                                            | $1.4 \times 10^{27}$ atoms<br>$7 \times 10^5$ g.<br>$6.67 \times 10^7$ curies<br>$8.4 \times 10^{24}$ Mev.   |
| Total amount of radioactive products          | $8.27 \times 10^6$ curies                                                                                    | $8.8 \times 10^7$ curies                                                                                     |
| Energy of radioactive products                | $2.5 \times 10^{26}$ Mev.                                                                                    | $7.5 \times 10^{26}$ Mev.                                                                                    |

\* The quantities given in this and other tables without indication of source have been obtained from well-known published statistics.

Table 2

Characteristic of the radioactive products of an explosion

|                                                                                                                           | Cs-137                | Sr-90                 | C-14                   | H-3                    |
|---------------------------------------------------------------------------------------------------------------------------|-----------------------|-----------------------|------------------------|------------------------|
| Decay period (years)                                                                                                      | 47.6                  | 40                    | 6,100                  | 18                     |
| Quanta energy and mean energy of beta particles per disintegration (Mev.)                                                 | 0.61*                 | Nil                   | Nil                    | Nil                    |
| Dose from 1 atom to 1 g. of tissue (rad./year)                                                                            | -                     | -                     | $3.05 \times 10^{-15}$ | $5.82 \times 10^{-12}$ |
| Dose from $10^{-12}$ curie to 1 g. of tissue (rad/yr)                                                                     | $1.12 \times 10^{-2}$ | $1.96 \times 10^{-2}$ | -                      | -                      |
| Dose, to 1 g. of bone tissue***                                                                                           | -                     | $9.3 \times 10^{-2}$  | -                      | -                      |
| Number of micromicrocuries to 1 g. of tissue releasing the maximum permissible dose 1.8 r/year ( $A_{90}$ )               | 100                   | 100                   | -                      | -                      |
| Dose, to the bones                                                                                                        | 100                   | 80                    | -                      | -                      |
| Number of micromicrocuries per gramme of carrier in the organism, releasing the maximum dose 1.8 r/year**** ( $A_{90}$ ): |                       |                       |                        |                        |
| To the bones                                                                                                              | -                     | 140                   | -                      | -                      |
| To other tissues                                                                                                          | $6.85 \times 10^4$    | $1.16 \times 10^6$    | -                      | -                      |

\* The mean energy released to 1 g. of tissue per disintegration, allowing for incomplete absorption of gamma rays in the organism, equals 0.6 Mev.

\*\* Instead of the roentgen which is equivalent to 85 ergs/g of water, the rad, equivalent to 100 ergs/g of tissue, is used. No distinction will be made between them in calculations.

\*\*\* Since strontium is deposited unequally in bone tissue, the local concentration may be 5 times greater than the mean.

\*\*\*\* Here, by carrier is meant elements with similar chemical properties: potassium for Cs-137 and calcium for Sr-90.

### 2. Method of calculating the dose rate from C-14 and H-3

C-14 and H-3 are always present in nature. They are formed in the atmosphere by the action of cosmic rays. The total amount of these elements is in equilibrium, i.e., it is equal to the rate of formation multiplied by the period of decay. The concentration of C-14 is uniform in various compounds of living and non-living matter which contain exchange carbon.

Water of atmospheric origin contains a specific concentration of H-3. All carbon-bearing matter (containing exchange carbon) on the surface of the earth contains a specific concentration of C-14. Water and carbon, two constituents of the human body, should contain the same concentration of C-14 and H-3 as that in food stuffs.

After an explosion, the total amount of C-14 and H-3 in nature will increase by  $1 + \frac{A}{A_0}$  times (A being the equilibrium amount of C-14 or H-3 present in nature before the explosion; A is the amount of C-14 or H-3 formed during the explosion). As a result, a new equilibrium concentration of isotopes,  $1 + \frac{A}{A_0}$  times greater than the previous concentration, will be established in foodstuffs and, consequently in the human body.

Since the dose rate from radioactive isotopes in tissue is proportional to their concentration, the dose rate after the explosion will be  $1 + \frac{A}{A_0}$  times greater than the rate from the natural concentration of C-14 and H-3.

Let  $r_0$  stand for the dose rate from the natural concentration of C-14 or H-3. The dose rate to the tissues from radioactive isotopes formed during the explosion will therefore be:

$$r = r_0 \times \frac{A}{A_0} \quad (1)$$

Table 3 illustrates the incidence of C-14 and H-3 in nature.

Table 3

Incidence of C-14 and H-3 in nature

|                                                                                                                                   | C-14                             | H-3                        |
|-----------------------------------------------------------------------------------------------------------------------------------|----------------------------------|----------------------------|
| Rate of formation in the atmosphere (g/year)                                                                                      | $10^{4*}$ (5), (5)               | 100 (4)                    |
| Total amount on the earth (in g.) $\Delta^{**}$                                                                                   | $81 \times 10^6$                 | 1800                       |
| Ditto, excluding the oceans (in the atmosphere, part of the biosphere, rivers) $\Delta^{\dagger}$                                 | $10 \times 10^6$ (5),<br>(5)     | 24 (4)                     |
| Relative increase in the amount of isotopes in nature as the result of a pure hydrogen explosion, $\Delta\Delta/\Delta^{\dagger}$ | $4.1 \times 10^{-5}$             | 5.9***                     |
| Ditto, but only in respect of isotopes elsewhere than in the oceans, $\Delta\Delta/\Delta^{\dagger}$                              | $85 \times 10^{-5}$              | 290                        |
| Natural atomic concentration of isotopes in plants (C-14) and river water (H-3)                                                   | $1.4 \times 10^{-12****}$<br>(5) | $5 \times 10^{-18}$<br>(2) |

\* Equal to 2.7 neutrons absorbed in the atmosphere per second over square centimetre of the earth's surface.

\*\* Obtained by multiplying the rate of formation in the atmosphere by the period of decay.

\*\*\* In systematic measurements, the increase in the amount of H-3 in nature formed as a result of explosions should be noted.

\*\*\*\* Equal to 16 disintegrations of C-14 per minute per gramme of C-12 (5).

Table 4

Dose rate from natural amounts of C-14 and H-3 in the tissues

| Number of atoms in 1 gramme of tissue (6) | Number of atoms of radioactive isotopes in 1 gramme of tissue | Dose from 1 atom to 1 gramme of tissue r/year | Dose from the natural amount of isotopes $r_0$ , r/year |
|-------------------------------------------|---------------------------------------------------------------|-----------------------------------------------|---------------------------------------------------------|
| H - $6.6 \times 10^{22}$                  | $5.5 \times 10^5$                                             | $5.52 \times 10^{-12}$                        | $1.8 \times 10^{-6}$                                    |
| C - $1 \times 10^{22}$                    | $1.4 \times 10^{10}$                                          | $1.05 \times 10^{-15}$                        | $1.5 \times 10^{-5}$                                    |

\* External radiation from natural C-14 from  $\text{CO}_2$  in the air gives a dose of  $10^{-6}$  r/year to the surface layers and is disregarded.

If it is assumed that the concentration of H-3 in the water medium of the organism is the same as that in river water, and that the organism consists mainly of water (hydrogen chemically linked in the tissues is disregarded), the amount of H-3 per gramme of tissue water can be found. We similarly assume that the concentration of C-14 in the body tissues is the same as that in the biosphere.

The composition of tissue and the value of  $r_0$  are shown in Table 4

By substituting in equation (1) the value of  $r_0$  from Table 4 and the value of  $\frac{AA}{A}$  from Table 3, we obtain the desired values for the dose rate to the tissues from the radioactive products of 10 megaton pure hydrogen explosion.

If distribution in the air, the biosphere and the ocean is uniform,

$$\begin{aligned} rC^{14} &= 1.5 \times 10^{-3} \times 4.1 \times 10^{-3} = 6 \times 10^{-6} \text{ r/year;} \\ rH^3 &= 1.8 \times 10^{-6} \times 3.9 = 7 \times 10^{-6} \text{ r/year.} \end{aligned} \quad (2)$$

The integral dose rate of internal radiation is  $13 \times 10^{-6}$  r/year.

In the case of decelerated mutual interaction with the ocean:

$$\begin{aligned} rC^{14} &= 1.5 \times 10^{-3} \times 33 \times 10^{-3} = 50 \times 10^{-6} \text{ r/year;} \\ rH^3 &= 1.8 \times 10^{-6} \times 290 = 523 \times 10^{-6} \text{ r/year} \end{aligned} \quad (2')$$

The integral dose rate of internal radiation is  $573 \times 10^{-6}$  r/year\*, i.e. forty times greater than in the case of the rapid absorption of the elements by the ocean.

\* The validity of this estimate is uncertain owing to the absence of data on the kinetics of the establishment of C-14 and H-3 distribution. In calculating the dose rate it is essential to know whether equilibrium with the ocean is established when the isotopes intermingle in nature. The ocean absorbs most of the C-14 and H-3 that is formed and removes it from the biosphere. Therefore, if distribution in the ocean takes place much more slowly than distribution in the air and the terrestrial part of the biosphere, the total quantity of products formed will be distributed only in the atmosphere, rivers and the terrestrial part of the biosphere, and the increase in their concentration  $\frac{AA}{A}$ , and, consequently, the dose rate will be correspondingly greater.

In future computations, only estimates based on the assumption that the radioisotopes are distributed uniformly in the air, the biosphere and the ocean, will be used.

It should be noted that radiation from C-14 will continue and produce its effects for thousands of years after the explosion, whereas H-3, Cs-137 and Sr-90 will decay in a hundred years. To determine the effects on the generation during whose lifetime the explosion took place, it is essential to know the dose rates during the first fifty years; for this the kinetics of the absorption of radioisotopes by the ocean are very important. However, for purposes comparing the effects corresponding to the radiation dose (total number of mutations and leukemias), the essential factor is the amount of the integral dose over the whole period of irradiation, which, in the case of C-14, is measured in thousands of years; for this reason it must be assumed that the radioisotopes are distributed uniformly in nature.

Assuming that the fall-out of H-3 onto the surface of the earth will continue for the same period as that of Sr-90 (10 years) and allowing for the rate of decay of H-3, the dose from H-3 over the whole period of irradiation will be:

$$\begin{aligned} H^3 &= 7 \times 10^{-6} \text{ r} \times 11.6 \text{ years} = \\ &= 81 \times 10^{-6} \text{ r}^*, \end{aligned}$$

and from C-14:

$$\begin{aligned} C^{14} &= 6 \times 10^{-6} \text{ r} \times 8.1 \times 10^3 \text{ years} = \\ &= 49,000 \times 10^{-6} \text{ r}^{**} \end{aligned}$$

In the case of a fission bomb the dose from C-14 will be seven times less i.e.  $7,000 \times 10^{-6} \text{ r}$

\* The dose is 1.13 times less over a period of forty years.

\*\* The dose during the first forty years is  $180 \times 10^{-6} \text{ r}$ , if it is assumed that the dissemination from the stratosphere is similar to that of Sr-90 (with a relaxation time of ~10 years).

3. Method of calculating the dose rates from Sr-90 and Cs-137

The following symbols will be used:

$Q(t)$  - the amount of the radioisotope deposited on the earth, corresponding to the complete precipitation of fission fragments as the result of a Q-megaton explosion;

$Q_0$  - the amount of the radioisotope formed during the explosion;

$T_d$  - period of decay of the radioisotope\*;

$T_f$  - period of fall-out to earth;

$T_{ef}$  - effective period of fall-out from the stratosphere

$$(T_{ef} = \frac{T_d \cdot T_f}{T_d - T_f}, T_f = 10 \text{ years}); **$$

$T_b$  - period of elimination of the radioisotope from the body;

$T_{eb}$  - effective period of elimination from the body

$$(T_{eb} = \frac{T_d \cdot T_b}{T_d - T_b});$$

$\checkmark$  - quantity of the radioisotope which annually enters the critical organ in fall-out to earth corresponding to 1 megaton (in micromicrocuries/year x megaton);

$q(t)$  - amount of the radioisotope in the organ (in micromicrocuries);

$M$  - mass of the organ, tissue or carrier element (in grammes);

$A_{dt}$  - maximum permissible concentration of the radioisotope at which the dose rate is equal to 1.8 r/year (in micromicrocuries per gramme of tissue) (see table 2);

$A_{dc}$  - ditto, in micromicrocuries per gramme of carrier;

\* In all calculations e-periods are used to express the value of  $T$ , i.e. the time during which the original amount of the isotope is reduced e times.

\*\* Little study has been made of the process of radioisotope fall-out from the stratosphere. In the present state of knowledge it may be assumed, with Libby (10), that fall-out takes place exponentially with a period of ten years.

$A_d$  - ditto, without indication of units used (choice of units depends on the units used to express  $M$ );

$a(t)$  - concentration of the radioisotope in the tissue (in micromicrocuri per gramme of tissue),

$$a(t) = \frac{q(t)}{M}.$$

The dose rate to the tissue is:

$$r(t) = \frac{a(t)}{A_d} \times 1.8 \frac{r}{\text{year}} = \frac{q(t)}{A_d M} \times 1.8 \times \frac{r}{\text{year}}. \quad (3)$$

The dose to the tissue is:

$$D(t) = \int r dt = \frac{1.8}{A_d M} \times \int q dt. \quad (4)$$

$q(t)$  will be found from the equation:

$$\frac{dq}{dt} = \checkmark Q - \frac{q}{T_{eb}}; Q = Q_0 (e^{-t/T_d} - e^{-t/T_{ef}}), \quad (5)$$

$$q = \checkmark \times Q_0 \times T_{eb} \times f(t), \quad (6)$$

where

$$f(t) = \left[ \frac{T_d \times e^{-t/T_d} - T_{ef} e^{-t/T_{ef}}}{T_d - T_{eb}} - \frac{T_{ef} e^{-t/T_{ef}}}{T_{ef} - T_{eb}} - \left( \frac{T_d}{T_d - T_{eb}} - \frac{T_{ef}}{T_{ef} - T_{eb}} \right) e^{-t/T_{eb}} \right] \quad (6a)$$

On integration, we obtain;

$$\text{for Cs-137: } D_{Cs} = \frac{1.8}{A_d M} \checkmark \times Q_0 T_{eb} \times 39.3; ** \quad (7)$$

$$\text{for Sr-90: } D_{Sr} = \frac{1.8}{A_d M} \checkmark \times Q_0 \times T_{eb} \times 32.2$$

$$* \text{ In continuing tests } q(t) = \checkmark T_{eb} Q f(t). \quad (6b)$$

\*\* The dose will be 1.5 times less over a period of 40 years.



The value of  $\sqrt{}$  (the quantity of the radioisotope which annually enters the critical organ) may be found in two ways.

1. From experimental data on the quantity of the radioisotope deposited in the human body as a result of large atomic explosions since 1952.

If the quantity of the radioisotope in the organism, measured at time  $t_0$  (beginning with 1952), is  $q(t_0)$ , then by using equation (6b), we find  $\sqrt{}$  or  $\sqrt{}$   $\times T_{eb}$ :

$$\sqrt{ } \times T_{eb} = \frac{q(t_0)}{Q_0 F(t)} \times \frac{q(t_0)}{350 F(t_0)} \quad (8)$$

Since the experimental data relate not to a random explosion but to continuing tests,  $Q_0$  in equation (6) must be replaced by  $Q_{\infty}$ , which represents the maximum value of the fall-out to the earth in the case of tests of infinite duration and constant intensity (6b). It can be shown that in the case of Sr-90,  $Q_{\infty} = 350$  megatons at a testing rate of 11 megatons per year.

2. From the known concentration of the radioisotope in the soil and the "protection coefficients" which govern the reduction in concentration during passage from the soil to the human organism, allowing for the fact that cesium enters the organism together with potassium, and strontium together with calcium.

Since the chemical properties of cesium and potassium, strontium and calcium are not completely identical, the proportion of the radioisotope in their carriers (potassium and calcium) in the soil and in the human body is not the same:

$$\left( \frac{Sr}{Ca} \right)_{\text{tissue}} = \left( \frac{Sr}{Ca} \right)_{\text{soil}} \times K,$$

where  $K$  is the integral protection coefficient ( $K = k_1 k_2 k_3 k_4$ ;

$k_1$  represents the soil-to-plant transfer,  $k_2$  the plant-to-food (milk, meat, etc.) transfer,  $k_3$  the food-to-blood transfer, and  $k_4$  the blood-to-tissue transfer).

It is obvious that the more calcium or potassium there is in the soil, the less there will be of the radioisotope in the body. The values for  $K$  may be extremely small (for strontium it is  $\sim 0.02$ ):

$$\sqrt{ } = AKm, \quad (9)$$

where  $A$  is the amount of the radioactive substance in micromicrocuries per gramme of the carrier present in a tilled layer of soil as the result of the world-wide fall-out of a quantity of the isotope corresponding to a 1-megaton-equivalent to one megaton (the depth of a tilled layer of soil is assumed to be 10 to 15 cm);  $m$  is the consumption of the carrier element ( $K, Ca$ ) by a person (in grammes per year).

Calculation of the gonadal dose from Sr-90\*. Experimental data obtained at the end of 1955 on the Sr-90 content of skeletons have been published (7).

At the end of 1955 the average Sr-90 content of soil throughout the world was 3.2 millicuries per square kilometre (7) which is approximately equal to the total Sr-90 fall-out from a 10-megaton-equivalent atomic bomb explosion (2.9 millicuries per square kilometre). At the same time the average Sr-90 content of bones throughout the world was found to be 0.3 micromicrocuries per gramme of Ca. This figure is for children up to four years of age in whom calcium exchange is most intensive and who had lived the greater part of their lives after the first large United States explosions (1952-1953). The figure is three times larger than the average for all ages, which is 0.1 micromicrocuries per gramme of Ca.

In this case  $t_0 = 4$  years; therefore  $F(t) = 0.0025$ . Substituting this value for  $F(t_0)$  in equation (8), we obtain:

$$\begin{aligned} \sqrt{ } \times T_{eb} &= \frac{q(t_0)}{350 F(t_0)} \\ &= \frac{0.3 \text{ g Ca M } (t_0)}{350 \times 0.0025} = \frac{\text{micromicrocurie}}{1 \text{ megaton/organism}} \end{aligned}$$

\* The value of  $\sqrt{}$  is obtained by the first method described above.

where  $M(t_0)$  represents the mass of the organ (the mass of calcium in the skeleton, in this case) at four years of age. Substituting the resultant value for  $\sqrt{T_{eb}}$  in equation (7) and assuming that

$$A_{dc} = 1.16 \times 10^6 \frac{\text{micromicrocuries}}{\text{gCa}} \quad (\text{See Table 2}):$$

$$D_b = \frac{1.8 \times M(t_0) \times 0.3 \times 32.2}{1.6 \times 10^{-6} \times M \times 350 \times 0.0025} \times 3^* = 128 \times 10^{-6} r$$

$\frac{M(t_0)}{M} = 1/4$  is the ratio of weights of calcium in infant and adult organisms).

Calculation of the dose to the bones from Sr-90. If, in equation (7), we insert the value for  $\sqrt{T_{eb}}$  obtained in section A, and assume that  $A_{dc} = 140$  micromicrocuries per gramme of Ca (see Table 2) and that

$$\frac{M(t_0)}{M} = 1/4, \text{ we obtain } D_b = 0.36 r$$

The mean dose rate is  $0.36 r/32.2 \text{ years} = 11.2 \text{ mr/year}$ .

This is the dose to the most highly irradiated parts, in which strontium accumulates. The mean dose to the bone tissue as a whole is one-fifth as large (international standard), i.e.  $0.072 r$ . In considering cases of leukaemia, the mean dose to the whole skeleton must be used (see Part 1).

Calculation of dose to the tissues from Cs-137. The value of  $\sqrt{T_{eb}}$  may be found by either of the methods described above; both calculations are given below:

1. At the end of 1956 it was determined by means of measurements carried out on living persons, that the concentration of caesium was 30 micromicrocuries per gramme of K (8). As the amount of fall-out on the surface of the earth in 1956 corresponded to 10 megatons and as the concentration referred to above was in equilibrium with this amount (period of elimination of potassium and caesium from the organism of infants: about one month for each),

\* The multiplier 3 is used because the value of  $a(t_0)$  was determined in respect of the bones, whose protection coefficient is 3 times that of the blood. The concentration in the blood and consequently in the gonads is 3 times greater than in the bones.

$$\sqrt{T_{eb}} = \frac{gK}{Q} = \frac{30 \frac{\text{micromicrocuries}}{\text{gK}} \times 140g}{10 \text{ megatons}} = \frac{420 \frac{\text{micromicrocuries}}{\text{gK}}}{1 \text{ megaton}}$$

(140 grammes being the amount of potassium in the organism) (9).

Inserting the value obtained in equation (7) and taking for  $A_{dc}$  the value given in Table 2 ( $6.85 \times 10^4 \frac{\text{micromicrocuries}}{\text{gK}}$ ), we get

$$D = \frac{1.8 \times 420 \times 10 \times 39.3}{6.85 \times 10^4 \times 140} = 31,000 \times 10^{-6} r.$$

The mean dose rate is  $750 \times 10^{-6} r$ .

2. By means of the measurements made by Gulyakin and Yudinseva (10) of the uptake of Cs-137, Sr-90, potassium and calcium in plants and the known protection coefficient in Sr-90 from soil to plant (0.7) (7) the soil-plant protection coefficient for Cs-137 can be computed. On the basis of these calculations this coefficient was found to be  $1/700$ .

$$\sqrt{T_{eb}} = AKm = \frac{1.57 \times 10^{17} \frac{\text{micromicrocuries}}{\text{megaton}} \times}{10^{-4} \frac{\text{gK}}{\text{g soil}} \times 5 \times 10^{18} \text{ cm}^2 \times 10 \text{ cm} \times 1.6 \frac{\text{g}}{\text{cm}^3}}$$

$$\times \frac{1}{700} \frac{1,000 \text{ gK}}{\text{year}} = 28.6 \frac{\text{micromicrocuries}}{\text{megaton} \times \text{year} \times \text{organism}};$$

$$\sqrt{T_{eb}} = 28.6 \times 6.85 \times 10^{-2} = 2 \frac{\text{micromicrocuries}}{\text{megaton} \times \text{organism}}$$

$$T_{eb} = 25 \text{ days} = 6.85 \times 10^{-2} \text{ years (8)}$$

Thus, on the basis of equation (7),

$$D = \frac{1.8 \times 2 \times 10 \times 39.3}{6.85 \times 10^4 \times 140} = 148 \times 10^{-6} r.$$

There is a considerable discrepancy between these two estimates - the first is 210 times greater than the second. This may be because caesium is deposited

\*  $T_{eb} \ll t, T_r, T_{ef}$ . In this case  $T_{eb} = \frac{g}{Q}$ .

upon foliage from which it is taken up by the plant, thus by-passing the soil. This method of uptake is very effective.

We consider the estimate obtained by the first method to be correct as it is based on direct measurements, and we shall use it hereafter.

Calculation of the dose to the bones from Cs-137. It is assumed that caesium is distributed uniformly throughout the bones together with potassium. The bones will then contain 1/30 of the total amount of caesium and

$$\sqrt{I_{eb}} = \frac{420}{30} = 14 \text{ micromicrocuries per megaton.}$$

Substituting this value in equation (7) and assuming that  $A_{dt} = 160 \frac{\text{micromicrocuries}}{\text{lg tissue}}$  and  $M = 10^4 \text{ g}$ , we find that  $D = 6,200 \times 10^{-6} \text{ r}$ .

Calculation of the external radiation dose from Cs-137 gamma rays. The external radiation dose can be calculated in accordance with the equation for the dose rate from a half-space (soil) with a uniform concentration of activity  $g \text{ Mev/cc.} \times \text{year}^{-1}$ :

$$r = d \times 1.48 \times 10^{-5} \mu\text{OEG} \frac{\lambda_{eff}}{2},$$

where  $\mu$  and  $\lambda_{eff}$  are the coefficients in the formal for the passage of Cs-137 gamma radiation through soil;  $1.48 \times 10^{-5}$  is the coefficient for the conversion of Mev/c.c. into r. The intensity of the radiation passing through the soil is therefore  $\mu \times e^{-\lambda/\lambda_{eff}}$  (where  $\lambda$  is the thickness of the layer of soil,  $\lambda = 1.3$  and  $\lambda_{eff} = 12 \text{ cm}$ );  $\mu\text{OEG}$  is the coefficient of energy absorption in air  $= 3.8 \times 10^{-5} \text{ cm}^{-1}$ . Thus

$$\frac{g\lambda_{eff}}{2} = \frac{Q_0 \times 3.7 \times 10^{10} \text{ sec}^{-1} \times 0.6 \text{ Mev}}{5 \times 10^{18} \text{ cm}^2 \times 15 \text{ cm} \times 2} \times$$

$$\times 12 \text{ cm} \times 3.15 \times 10^7 \frac{\text{sec}}{\text{year}} = 8.8 \times 10^4 \frac{\text{Mev}}{\text{cm}^2 \times \text{year}},$$

$$r = 64.3 \times 10^{-6} \left( e^{t/T_r} - e^{t/T_{ef}} \right) \text{ r/year.}$$

\*  $g \approx Q$ ; consequently, on the basis of equation (5),  $g = g_0 \left( e^{-t/T_r} - e^{-t/T_{ef}} \right)$

where  $5 \times 10^{18} \text{ cm}^2$  is the surface area of the soil, 15 cm is the thickness of the layer of soil containing the radioactive sources, and  $Q_0 = 1.57 \times 10^6$  curies is the energy equivalent of 10 megaton explosions (see Table 1). The external radiation dose throughout the whole period of Cs-137 decay is

$$\int_0^\infty r dt = 2540 \times 10^{-6}$$

#### 4. Comparison of doses during the life of the isotopes and estimate of the number of leukemias

Since the number of mutations is proportional to the integral dose received by the gonads, the integral radiation dose to the gonads during the life of the radioisotopes which is given in Table 5, can be used to compare the genetic effects of explosions of ordinary and deuterio-tritium bombs.

Table 5

Radiation doses to the gonads from explosions of atomic and pure hydrogen bombs

| Source of radiation                                | Doses, r                               |                                   |
|----------------------------------------------------|----------------------------------------|-----------------------------------|
|                                                    | Explosion of an ordinary (atomic) bomb | Explosion of a pure hydrogen bomb |
| Sr-90                                              | $128 \times 10^{-6}$                   | -                                 |
| Cs-137                                             | $31,000 \times 10^{-6}$                | -                                 |
| C-14                                               | $7,000 \times 10^{-6}$                 | $49,000 \times 10^{-6}$           |
| H-3                                                | -                                      | $81 \times 10^{-6}$               |
| Cs-137 (external)                                  | $2,540 \times 10^{-6}$                 | -                                 |
| Integral dose during the life of the radioisotopes | $41,000 \times 10^{-6}$                | $49,000 \times 10^{-6}$           |

The integral dose for the whole period of decay of the isotopes from a pure hydrogen bomb is close to that from an ordinary bomb. A similar picture is obtained from an examination of the tissue doses over the first thirty years after the explosion (see Table 5a).

Table 5a

| Radiation source | Doses, r                               |                                   |
|------------------|----------------------------------------|-----------------------------------|
|                  | Explosion of an ordinary (atomic) bomb | Explosion of a pure hydrogen bomb |
| Internal         | $15,000 \times 10^{-6}$                | $190 \times 10^{-6}$              |
| External         | $1,900 \times 10^{-6}$                 | $5,300 \times 10^{-6}$ *          |

\* The dose of  $5,300 \times 10^{-6}$  r is obtained on the assumption that in thirty years the ocean will be unable to absorb any considerable amount of  $C^{14}$ .

As time passes the dose rate will decline owing to  $Cs-137$ ,  $Sr-90$  and  $H-3$  decay. One hundred years or more after the explosion the only effect of partial significance will be that due to  $C-14$  activity, which will continue for many thousands of years.

We shall evaluate the genetic damage due to  $C-14$  released in a 10-megaton pure hydrogen-bomb explosion.

The integral number of mutant births during the period of decay of the isotopes is determined by the total dose\*\*, and can be computed by means of the genetic-damage coefficient (section 1).

\*\* The principle of the proportionality of the number of persons affected to the total dose over an infinite period is valid only if the time required for the establishment of an equilibrium concentration of the isotope in the organism is considerably less than the life of the organism, as in the case of  $C-14$ ,  $Cs-137$  and  $H-3$ . In the case of  $Sr-90$ , this condition is not satisfied so well, but calculations indicate that the error is small. For an accurate calculation of the number of persons affected, the age distribution of the population at the time of the explosion should be taken into account. In the case of a population of constant size consisting at the time of the explosion of two age groups (0 and 30 years), calculation shows the number of persons affected by  $Sr-90$  to be 1.3 times less than that computed according to equation (7).

In a population of  $2.5 \times 10^9$  persons the integral number of mutant births is:

$$\text{due to } C^{14}: 2.5 \times 10^9 \text{ persons} \times 4 \times 10^{-4} \frac{\text{mutants}}{\text{person} \times 1r} \times 49,000 \times 10^{-6} r = 49,000 \text{ persons};$$

$$\text{due to } H^3: 2.5 \times 10^9 \text{ persons} \times 4 \times 10^{-4} \frac{\text{mutants}}{\text{person} \times 1r} \times 81 \times 10^{-6} r = 81 \text{ persons.}$$

The total number of mutant births caused by a 10-megaton pure hydrogen bomb is 49,000.

A comparison with the figures in Table 5 shows that the explosion of a fission bomb causes the same number of cases of genetic damage as the explosion of a fusion bomb.

As regards non-genetic effects, a quantitative evaluation can be made only in respect of leukemias. The number of leukemias is proportionate to the radiation dose to the bones and amounts to  $1.2 \times 10^{-4}$  cases per person per r.

Table 6 shows the mean radiation doses to the bones during the life of the radioisotopes. In the explosion of an ordinary atomic bomb the majority of leukemias are induced during the first fifty years - the effective period of  $Sr-90$  and  $Cs-137$  activity. In the explosion of a pure hydrogen bomb, approximately the same number of leukemias are induced over thousands of years. It is assumed that the principle of the proportionality of the number of persons affected to the dose can be extended to the case of irradiation over thousands of years.

Table 6

## Mean doses to the bones

| Radiation source    | Doses to the bones, r                  |                                   |
|---------------------|----------------------------------------|-----------------------------------|
|                     | Explosion of an ordinary (atomic) bomb | Explosion of a pure hydrogen bomb |
| $Sr-90$             | $72,000 \times 10^{-6}$                | -                                 |
| $Cs-137$            | $6,200 \times 10^{-6}$                 | -                                 |
| $C-14$ *            | $7,000 \times 10^{-6}$                 | $49,000 \times 10^{-6}$           |
| $H-3$               | -                                      | disregarded                       |
| $Cs-137$ (external) | $2,540 \times 10^{-6}$                 | -                                 |

Integral dose to the bones

during the life of the

radioisotopes  $88,000 \times 10^{-6}$   $49,000 \times 10^{-6}$

\* The carbon content of the organic part of the skeleton is assumed to be the same as that of the tissues.

The total number of leukemias induced in a population of  $2.5 \times 10^9$  persons by the explosion of a 10-megaton pure hydrogen bomb is

$$2.5 \times 10^9 \text{ persons} \times 1.2 \times 10^{-4} \frac{\text{cases}}{\text{persons} \times \text{yr}} \approx 49,000 \times 10^{-6} = 15,000 \text{ persons.}$$

Table 6 indicates that the number of leukemias induced by the explosion of an ordinary atomic bomb is 26,000.

#### 5. Effects of a surface explosion of a pure hydrogen bomb

In the case of a surface explosion of a pure hydrogen bomb, additional radioactive materials are produced - the isotopes which are formed as the result of neutron capture by the soil. Most of the activity produced in this process is short-lived and may be disregarded. The activity of more than five years' duration is associated with the isotopes Co-60, Cs-137, Sm-151 and Eu-154, the last two of which, like strontium, accumulate in the bones. Because we lack sufficient systematized data on the incidence of these elements in nature and in human tissue and on their metabolism, we shall have to confine ourselves to a preliminary estimate for cobalt only.

We shall assume that the cobalt content of the soil is one in  $10^5$  parts and that of animal tissue one in  $10^6$  parts (BSE, Vol. 21, 1957, p. 489). One Mev of energy is absorbed by the tissue per disintegration and the period of decay is eight years\*. The proportion of radioactive cobalt in the organism will be equal to that of radioactive cobalt in the soil as a whole. The latter is equal

\* i.e. the  $\tau$  period.

to the ratio of the number of radioactive cobalt atoms formed to the number of cobalt atoms in the surface layer of the earth's soil. The neutron capture cross-section of cobalt per gramme of soil is  $10^{-5} \frac{\text{cm}^2}{\text{g soil}} \times 10^{22}$

$$\text{atoms/g} \times 60 \times 10^{-24} \text{ cm}^2/\text{atoms} = 6 \times 10^{-6} \text{ cm}^2/\text{g}.$$

Since the capture cross-section of soil is  $5 \times 10^{-3} \text{ cm}^2/\text{g}$ , the cobalt will capture  $\frac{6 \times 10^{-6}}{5 \times 10^{-3}} = 10^{-3}$  of all neutrons, as a result of which  $0.5 \times 10^{28}$

$\times 10^{-3} = 5 \times 10^{24}$  atoms of radioactive cobalt are formed. A layer of soil of thickness 20 g/cm<sup>2</sup> on the earth's surface would contain  $5 \times 10^{18} \text{ cm}^2 \times 20 \text{ g/cm}^2 \times 10^{-5} = 10^{15}$  grammes of cobalt, i.e.  $\frac{10^{15} \times 6 \times 10^{23}}{60} = 10^{37}$  atoms of cobalt.

Thus the proportion of radioactive cobalt to the total amount of cobalt would be  $\frac{5 \times 10^{24}}{10^{37}} = 5 \times 10^{-13}$ . Consequently, when equilibrium is achieved, the animal organism will contain  $10^{-6} \times 5 \times 10^{-13} = 5 \times 10^{-19}$  grammes of radioactive cobalt per gramme of tissue, i.e.

$$5 \times \frac{10^{-19}}{60} \times 6 \times 10^{23} = 5 \times 10^3 \frac{\text{atoms}}{\text{g}} \text{ Co}^{60}.$$

The dose rate from cobalt is  $5 \times 10^3 \text{ atoms/g} \times 1 \text{ Mev/atom} \times 1.6 \times 10^{-6} \text{ erg/Mev} \times 10^{-2} \text{ r/erg} = 11 \times 10^{-6} \text{ r/year**}$ . The dose during the period of decay is  $90 \times 10^{-6} \text{ r}$ . The cobalt contribution is therefore small.

The behaviour of Sm-151 and Eu-154 is interesting because, like Sr-90, they accumulate in the bones and are not eliminated (however, their coefficient of ingestion per unit intake of food is one-thousandth that of Sr-90 (11)).

In the case of fission or pure hydrogen bombs other than those discussed in this paper, the size of the doses and the estimated effects will vary in proportion to the number of fissions and the number of neutrons formed during the explosion.

\* Fifty per cent of all neutrons are captured by the soil.

\*\* This figure is high because: (1) neutron capture takes place in a layer of soil of thickness 15 cm, not all of which is taken into the stratosphere; and (2) the fall-out of soil particles is more rapid. Less Co-60 will therefore be scattered. Over a limited area the dose from Co-60 may be considerable.

## CONCLUSIONS

In its harmful effects (number of mutant births and leukemias) judged according to the size of the dose, a pure hydrogen (deutero-tritium) bomb is just as dangerous as an ordinary fission bomb, but its effects will be produced over a longer period.

The total number of persons suffering genetic damage as the result of the explosion of a 10-megaton pure hydrogen bomb in a population of  $2.5 \times 10^9$  persons is estimated at 49,000, and, through the explosion of an ordinary atomic bomb, at 41,000. The total number of leukemias induced by the explosion of a 10-megaton pure hydrogen bomb is estimated at 15,000 and by that of an ordinary atomic bomb at 26,000.

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### HAZARD TO MAN OF CARBON 14

#### WHAT PROBLEMS ARE ENCOUNTERED IN THE QUANTITATIVE ESTIMATION OF THE BIOLOGICAL HAZARDS OF CARBON-14?

(John R. Totter, M. R. Zelle, H. Hollister<sup>1</sup>)

Carbon-14 is an isotope of the chemical element carbon. As such, it forms the same chemical compounds and, as part of the organic molecules built around the carbon atom, becomes part of living tissue. Carbon-14, though virtually indistinguishable chemically from the other isotopes of carbon, is radioactive, emitting low-energy beta particles (0.05 Mev average) and having a half-life of about 5600 years. Therefore, carbon-14 is a potential hazard to man, for in his body it is emitting radiation that can affect living cells and, additionally, is itself undergoing change—transmutation—by decay to another element, nitrogen, of different chemical characteristics.

This article considers briefly some of the problems encountered in the quantitative estimation of the biological hazards to man of carbon-14.

#### Possible Mutagenic Effect of Carbon-14 Transmutation

Most discussions of the genetic effects of radioactive isotopes present in the body have considered only the effects of the radiation emitted during radioactive decay. However, the transmutation of radioactive atoms which have been incorporated into the genetic material, deoxyribonucleic acid (DNA), may also result in mutations. Radioactive isotopes of carbon, phosphorus, and hydrogen must all be considered, but, since nuclear detonations may produce appreciable amounts of carbon-14, this long-lived isotope is of particular concern. On the molecular scale, mutations are believed to be changes in the chemical structure of DNA.

When a carbon-14 atom contained in DNA decays to nitrogen-14 by the emission of a beta particle, a mutation could result in two ways: (i) by a radiochemical change in DNA caused by either the beta particle emitted or by recoil of the nucleus and (ii) as a result of the carbon-14 to nitrogen-14 transmutation itself, which almost certainly would cause a chemical change in the DNA molecule in which it occurred. Since all DNA is contained in the chromosomes and is genetically active, it is possible that almost all such transmutations occurring in DNA would cause mutations. On the other hand, it is conceivable that the chemical changes caused by transmutation of carbon-14 in DNA would prevent the successful duplication of the DNA and hence would be lethal to the cell in which the transmutation occurred, with the result that no detectable mutations would be produced.

There are almost no data as yet on which to base an estimate of the magnitude of the transmutation effect. Experiments made to obtain such data must be carefully planned to differentiate between mutations produced by the two processes and are complicated further by the long half-life and low specific activity of the available carbon-14 isotope preparations. Certain micro-organisms appear to offer the most promising experimental approach.

The natural carbon-14 content of the biosphere is given by Anderson (1) as  $1.46 \times 10^{-12}$  times the total carbon content. The three isotopes of carbon are uniformly distributed in the atmosphere and in living organisms, so one can estimate the contribution which the disintegration of carbon-14 makes to the total radiation dose. Since the transmutation of an element such as carbon or phosphorus in the chain of DNA is probably much more effective in producing biological damage, the carbon-14 content of DNA is of interest.

Mammalian diploid cells contain 8 to  $7 \times 10^{-12}$  gram of DNA per cell (2) and DNA is approximately 37 percent carbon. Therefore each diploid cell contains about  $2.4 \times 10^{-13}$  gram of DNA carbon. A carbon atom weighs  $12/(6 \times 10^{23}) = 2 \times 10^{-23}$  gram, and each diploid cell's DNA should contain  $(2.4 \times 10^{-13}) / (2 \times 10^{-23}) = 1.2 \times 10^{10}$  atoms. The carbon-14 content is  $1.2 \times 10^{10} \times 1.28 \times 10^{-12} = 1.54 \times 10^{-2}$  atom

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per cell in DNA. That is, on the average, about one in six cells should contain a carbon-14 atom in the DNA.

The probability that each cell would suffer a carbon-14 transmutation is given by dividing the average life of carbon-14 (about 8000 years) into  $1.54 \times 10^{-2}$ :

$$\frac{1.54 \times 10^{-2}}{8.0 \times 10^3 \text{ yr}} = 1.9 \times 10^{-6}$$

per year. The generative cells may be assumed, on the average, to have accumulated 30 years of this kind of damage at conception time. That is, the probability that any given generative cell has had a carbon-14 transmutation in its genetic material is  $6 \times 10^{-6}$ .

With a birth rate of 30 per 1,000 and  $2.5 \times 10^9$  as the world population, the maximum genetic damage from carbon-14 transmutations in genetic material could result in the birth, each year, of  $2.5 \times 10^9 \times 3 \times 10^{-2} \times 6 \times 10^{-6} = 4.5 \times 10^4$  persons with mutated genes. This assumes a ratio of 1 for the fraction mutations/transmutations ( $M/T$ ).

In his estimates of fission-product and carbon-14 hazards, Leipunsky (3) assumed an increment of carbon-14 due to 10 megatons of fusion equal to  $4.1 \times 10^{-3}$  times the present carbon-14 equilibrium value. Such a value would yield  $4.1 \times 10^{-3} \times 4.5 \times 10^4 \times 8100 = 1,400,000$  persons with defective genes due to the carbon-14 increment. One-half of these defects would occur in the 5,600 years following the addition of the carbon-14 increment. It is possible that the value of  $4.1 \times 10^{-3}$  may be too large by a factor as great as 10. As was indicated by Libby (4), one-fourth of this value, or  $10^{-3}$ , would be more correct. If we were to assume a reduction by a factor of 10, the figures would reduce to a total of 144,000.

The fractional increase per year cannot be given because of the exponential decrease in carbon-14, but the maximum fractional increase due to fusion-produced carbon-14, assuming immediate complete mixing, would be 184/45,000 in one case and 18/45,000 in the other. This ratio, of course, is valid no matter what the value of  $M/T$ .

Some limits on the possible values of  $M/T$  may be set. Although it is conceivable that more than one mutant gene might result from one transmutation, this is not likely to be a frequent occurrence. Only about one-half of the carbon atoms of DNA are in the chain, and a fraction of the remaining half may be less likely to cause mutations when decay takes place. More important, the decays may be so effective as to totally inactivate the cell, in which case no mutation will result. Therefore, the upper limit would appear to be set safely at less than 1.

There appears to be no logical or experimental basis on which to base an estimate of the lower limit of the fraction  $M/T$ . When inactivation of *Neurospora* and bacterial viruses was measured (see 5), experimental values for phosphorus-32 decay were between 10 and 1,000 times greater than values for the probability of inactivation by comparable amounts of ionization. There appear to be no data for production of mutations by transmutation of carbon-14 or phosphorus-32 in DNA. McQuade, Friedkin, and Atchison (6) have provided data on chromosome aberrations due to thymidine-2-carbon-14 incorporation in which the carbon-14 decay in DNA appears to be at least 9 or 10 times as effective as decay in cytoplasm. However, the data are inconclusive, as was pointed out by the authors themselves.

It is of interest to calculate the value of  $M/T$  which would result in a mutation frequency due to carbon-14 transmutation in DNA which is equal to the mutation frequency from the ionization produced by carbon-14 decay outside the DNA. This value is equal to the ratio of beta radiation mutations to the mutations resulting from carbon-14 transmutations in DNA on the hypothesis that  $M/T=1$ . Leipunsky (3) estimated 40,000 mutations from beta radiation where our corresponding carbon-14 transmutation estimate is  $1.44 \times 10^6$ . This leads to  $M/T=0.034$  for the value for equal numbers of mutations for the two processes. If one uses more refined estimates of the carbon-14 beta radiation dose, this value would not be changed, since estimates of both the beta dose and the number of carbon-14 transmutations depend on the bomb-produced increment to the natural carbon-14 pool.

This ratio, 0.034, depends on beta-induced mutations of only one class, serious physical or mental defect, with an estimated normal frequency of 2 percent. If one includes all three classes of genetic damage considered by Crow (7), two

of which are partially overlapping, the value of  $M/T$  necessary for equal transmutation and beta-induced mutation frequencies is 0.66.

It is therefore concluded that, on the basis of limited experience in other organisms and with other isotopes, it is not unreasonable to assume that the number of mutations due to carbon-14 disintegration in DNA could be at least equal to, and could probably exceed, the number caused by the carbon-14 beta radiation.

There is some evidence that genes in different species differ in size and complexity. For example, Carter (8) estimates that each gene in the mouse is 19 times as large as a *Drosophila* gene. This estimate is based on comparative mutation rates and the 20-fold greater DNA content per diploid cell in mice. If this conclusion is correct, the value  $M/T$  for any species can be accurately determined only by experiment on that species, and the effects in mice and other mammals may be very much more serious than those in microorganisms, for example. However, the greater DNA content could conceivably consist largely of "nongenic" DNA, in which carbon-14 decay would be less apt to cause mutation. Thus, it is possible to do no more now than guess at the broad limits of the ratio  $M/T$ .

#### Numerical Estimation of Genetic Damage to Human Populations

With the advent of atomic and nuclear energy, the question of genetic hazards has become a matter of great importance, of almost universal interest, and of no little controversy. In the past 2 years there have been three comprehensive statements of the present status of knowledge concerning the problem (9-11), and there will soon be a fourth (12). All of these statements agree about the seriousness of the problem, about the lack of sufficient knowledge of human spontaneous and radiation-induced mutation rates to provide accurate numerical estimates of the hazards, and about the desirability of minimizing the exposure of human reproductive cells to radiation during the reproductive period. The reports are in agreement also on the conclusion that the linear mutation-dose relation observed in the range of 25 to several thousand roentgens in a number of species must be considered to extend through smaller doses to zero. In other words, it is concluded that there is no dose of radiation so small that it is not genetically harmful.

Since, therefore, the number of mutations induced is considered to be directly proportional to the radiation dose, it is possible to make crude numerical estimates of the hazards, provided information is available on the average dose to the gonads during the reproductive period. Many geneticists feel that it is unwise to make such calculations, since there is a very high degree of uncertainty in them and, consequently, the calculations may be quite misleading or may be misinterpreted. However, since such calculations have been and will be made frequently, it is important to recognize the assumptions on which they are based and the sources of uncertainty in the results.

The usual approach to the calculations involves use of the doubling dose, or that dose required to induce mutations at a rate equal to the spontaneous or natural rate. This dose is usually taken as 50 roentgens, although the National Academy of Sciences (9) and Medical Research Council (10) reports give only the range 30 to 80 roentgens. A draft of the more recent consideration by the United Nations Scientific Subcommittee (12) gives a range of 10 to 100 roentgens. This large factor of uncertainty must be constantly borne in mind when one is considering the results of such calculations.

The usual calculation is concerned only with rather gross, tangible genetic effects, as considered in the National Academy report (9), and ignores the completely recessive mutations or the probably much larger class of mutations with small effects which nevertheless are harmful. The estimates are therefore almost certainly underestimates of the total damage. It is also important to keep in mind the question of genetic equilibrium. With appropriate corrections for changes in population size, each unfavorable gene, no matter how large or small in effect, induced in a population must be balanced in a subsequent generation by an elimination of a gene descended from that gene; otherwise, the frequency of that gene will increase cumulatively. Reduced effective fertility is the mechanism by which such eliminations occur. This can be thought of as a reduction in the chance that individuals, starting at the time of fertilization of the egg, will complete normal reproductive cycles. Thus, in a population in equilibrium, the total of reductions in fertility could be estimated to a first approximation if all unfavorable mutations—regardless of the magnitude of their unfavorable effect—could be individually detected and counted.

Perhaps the most useful calculations which have been made are those of Crow in the Fallout Hearings (7). His estimates are shown in table 1. All of these estimates assume a 30-year dose to the gonads from fallout of 0.1 roentgen, as estimated in the National Academy report (9), a doubling dose of 50 roentgens, and a stable world population of  $2 \times 10^9$  births per generation.

TABLE 1.—Estimates of damages from fallout calculated by J. F. Crow and presented at hearings of the Special Subcommittee on Radiation, U.S. Congress, in 1957 (7)

| Kind of damage                           | Number           |         |
|------------------------------------------|------------------|---------|
|                                          | First generation | Total   |
| A. Gross physical or mental defect.....  | 8,000            | 80,000  |
| B. Stillbirths and childhood deaths..... | 20,000           | 300,000 |
| C. Embryonic and neonatal deaths.....    | 40,000           | 700,000 |

The gross physical or mental defect estimate ignored all completely recessive effects and assumed a normal incidence due to spontaneous mutation of 2 percent. This category roughly corresponds to the "tangible genetic defect" category of the National Academy report (9) and is perhaps the most useful kind of calculation for comparative purposes. The arithmetic is simple:

$$\frac{(0.1 \text{ r})}{(50 \text{ r})} (0.02) (2 \times 10^9) = 8 \times 10^4 \text{ (total)}$$

Stillbirths and childhood deaths were estimated from increased death rates in children of consanguineous marriages by Morton, Crow, and Muller (13), who give an estimate of 8 percent as the frequency at mutational equilibrium. As before, the total damage from 0.1 roentgen for a generation is obtained by

$$\frac{(0.1 \text{ r})}{(50 \text{ r})} (0.08) (2 \times 10^9) = 3.2 \times 10^5$$

This result was rounded to  $3 \times 10^5$ .

The estimates of embryonic and neonatal deaths were based on Russell's (14) observation of a 3 percent reduction in litter size of mice at 3 weeks of age when the sires had been exposed to 300 roentgens. If both parents received 0.1 roentgen, the effect would be 0.2/300 as great. Hence, the estimated first-generation effect is

$$\frac{(0.2)}{(300)} (.03) (2 \times 10^9) = 4 \times 10^4$$

If it is assumed that 6 percent are expressed in the first generation, as estimated for stillbirths and childhood deaths, the total damage is approximately  $6.7 \times 10^5$ , which rounds to  $7 \times 10^5$ .

It is interesting to observe at this point that, although the numbers 80,000, 300,000, and 700,000 are large and obviously serious when it is remembered they assume an average gonadal dose of only 0.1 roentgen per generation, the estimated increase in the first generation in each case is only  $10^{-4}$  of the normally occurring abnormalities. So small an increase would be impossible to detect experimentally. It is this apparent contradiction—large absolute numbers but small fractional increases—which leads to much of the controversy on this important question.

It is important to remember also that the second and third categories of damage are not mutually exclusive: stillbirths and infant deaths are included in both.

It is a simple matter to adjust Crow's figures for other doses or population sizes. This is illustrated in a later section, after a discussion of the gonadal exposures due to bomb-produced and natural carbon-14.

However, attention is again directed to the large uncertainty, perhaps as large as a factor of 10, in the doubling dose; this uncertainty, coupled with uncertainty in the spontaneous mutation rates, makes any conclusions that are drawn from such calculations correspondingly uncertain with respect to absolute magnitude. Even so, such calculations can be useful for comparative purposes, since these



uncertainties affect each calculation equally and hence essentially cancel out. Therefore, the largest uncertainty in such comparisons derives from the calculations of the relative gonadal doses and, in the case of certain isotopes, our almost complete lack of information about the magnitude of the transmutation effect. It should also be borne in mind that estimates of "serious physical or mental defect," in Crow's terms (7), or of "tangible genetic defect," in the language of the National Academy report (9), do not measure the total genetic damage because certain categories of genetic damage are omitted from these calculations.

#### Biological Hazards

**The natural occurrence of carbon-14.** Carbon-14 is produced in nature in amounts estimated (9) to be from 7 to 10 kilograms per year by the absorption of cosmic ray neutrons in the atmosphere. It exists in the atmosphere as radioactive carbon dioxide and as such takes part in the overall carbon cycle of the earth, mixing with ocean water (existing there as a carbonate or bicarbonate) and with the biosphere (plants and animals) and entering man. Because carbon-14 appears to have existed naturally for millions of years or more, it now exists on earth in essentially a constant quantity (15): whatever is made each year only compensates, approximately, for what decays. Estimates of the amount of naturally existing carbon-14 in the total earth reservoir (ocean, biosphere, and atmosphere) range from about 56 to 81 metric tons by weight (3, 9, 15).

The approximate distribution of the 56 to 81 metric tons of natural carbon-14 in the earth's reservoir is shown in table 2 (9). Because the distribution as well as the quantity of natural carbon-14 is important, table 3, based on data presented by Arnold and Anderson (15), is presented to give an estimate of the distribution of all carbon in the earth's reservoir.

In all precise estimates of the natural background radiation dose to man, the contribution of natural carbon-14 is included, although its contributions to the estimated annual background dose of 100 to 150 milliroentgens (9, 16) is only about 1 percent (16).

**Production of carbon-14 by nuclear weapon explosions.** All nuclear weapons involve in their nuclear reactions the production of neutrons. Some of the neutrons are used in fission chain reactions resulting in the formation of radioactive fission products such as strontium-90, iodine-131, and cesium-137. The neutrons themselves would be of no concern, from the standpoint of hazards, were it not for the fact that some of them escape from the weapon to the outside environment. These neutrons of various energies are eventually captured; it is estimated that, for an air burst more than a few hundred meters above the ground, more than 95 percent of the neutrons eventually react with the nitrogen nuclei of the atmosphere and produce carbon-14. If the detonations are on the surface, then roughly one-half of the neutrons would not be absorbed in nitrogen atoms to make carbon-14, by the same token, would induce radioactivity of relatively short half-life in the soil.

For United States nuclear weapons of all types (17), roughly equal numbers of neutrons escape per unit of energy yield ("kiloton" or "megaton"). Therefore, two nuclear weapons, regardless of type but of the same yield and detonated under the same conditions, will produce roughly equal amounts and types of neutron-induced radioactive materials, including carbon-14, if the burst is such that neutrons escape to the air.

In a recent speech, Libby (4) stated: "At a rate of 2.5 neutrons [escaping] per 200 Mev of energy release, one megaton would generate  $3.2 \times 10^{16}$  carbon-14 atoms. The best estimate, keeping in mind that a substantial amount [of the carbon-14 produced] falls back as calcium carbonate, would be that about  $10^{16}$  carbon-14 atoms have been introduced into the atmosphere [from weapon testing to date], mostly into the stratosphere. The estimate of 2.5 neutrons per 200 Mev energy released is higher than an earlier estimate based on an assumed 15 percent escape efficiency [(17)], the later value being based on firmer information. It also attempts to weigh fusion and fission as they have actually occurred."

Leipunsky (3) has assumed for his fusion weapon one employing only deuterium-tritium fusion reactions and allowing all neutrons produced to escape to their environment. His estimate of the number of escaping neutrons per 200 Mev may be too high by a factor of 4 to 6 compared with like estimates for U.S. weapons.

The calcium carbonate represents an addition to the earth's carbon-14 reservoir too, but in a chemical form such that the radiocarbon cannot exchange readily with the biosphere. One might note that  $3.2 \times 10^{16}$  carbon-14 atoms is about 7.4 kilograms and that  $10^{16}$  carbon-14 atoms is about 230 kilograms. The addition of 230 kilograms (0.23 metric tons) of bomb-produced carbon-14 to date thus means an addition of 0.3 to 0.4 percent to the total carbon-14 reservoir.

TABLE 2.—Approximate distribution of natural carbon 14 in the earth's reservoir

| Reservoir                                 | Carbon 14   |         |
|-------------------------------------------|-------------|---------|
|                                           | Metric tons | Percent |
| Atmospheric CO <sub>2</sub> .....         | 0.96        | 1.69    |
| Terrestrial living matter plus humus..... | 2.2         | 3.88    |
| Ocean: total organic matter.....          | 3.8         | 6.7     |
| Ocean: total inorganic matter.....        | 49.8        | 87.6    |
| Total.....                                | 56.8        | 100.07  |

TABLE 3.—Estimated distribution of all carbon in the earth's reservoir

| Reservoir                                 | Percent |
|-------------------------------------------|---------|
| Atmospheric CO <sub>2</sub> .....         | 1.47    |
| Terrestrial living matter plus humus..... | 2.83    |
| Ocean: total organic matter.....          | 8.61    |
| Ocean: total inorganic matter.....        | 87.2    |
| Total.....                                | 100.11  |

TABLE 4.—Estimates of total genetic hazards of bomb-produced and natural carbon 14 and natural background radiation

[To estimate the hazard for the next 5,000 years, divide these numbers by 2. Categories B and C are partially overlapping]

#### A. GROSS PHYSICAL OR MENTAL DEFECT

| Bomb C <sup>14</sup> to date (dose: 0.026 mr/yr) |                                       | Natural background radiation |                                       |                         |                                       |
|--------------------------------------------------|---------------------------------------|------------------------------|---------------------------------------|-------------------------|---------------------------------------|
|                                                  |                                       | Carbon 14 (dose: 1.5 mr/yr)  |                                       | Total (dose: 150 mr/yr) |                                       |
| Persons (number)                                 | Fraction of total population affected | Persons (number)             | Fraction of total population affected | Persons (number)        | Fraction of total population affected |
| $1.0 \times 10^6$ .....                          | 1/5,340,000                           | $1.92 \times 10^7$           | 1/27,800                              | $9.6 \times 10^4$       | 1/556                                 |

#### B. STILLBIRTHS AND CHILDHOOD DEATHS

|                         |             |                   |         |                   |       |
|-------------------------|-------------|-------------------|---------|-------------------|-------|
| $3.8 \times 10^6$ ..... | 1/1,400,000 | $7.2 \times 10^7$ | 1/7,400 | $3.6 \times 10^6$ | 1/168 |
|-------------------------|-------------|-------------------|---------|-------------------|-------|

#### C. EMBRYONIC AND NEONATAL DEATHS

|                         |           |                    |         |                   |      |
|-------------------------|-----------|--------------------|---------|-------------------|------|
| $9.0 \times 10^6$ ..... | 1/593,000 | $1.68 \times 10^8$ | 1/1,785 | $8.4 \times 10^6$ | 1/64 |
|-------------------------|-----------|--------------------|---------|-------------------|------|

However, this addition is not instantaneously uniform throughout the whole reservoir, for equilibrating time must be taken into account. All of the bomb-produced carbon-14, at the time it is produced, is in the atmosphere except for the direct fallback of calcium carbonate. The bomb-produced carbon-14 present in the atmosphere as carbon-14 dioxide can exchange with the biosphere and with the ocean. The higher the concentration of carbon-14 in the atmosphere, the higher will be the resulting concentration in plants after exchange. Even-

tually the exchange with the ocean will reduce the atmospheric level of bomb-produced carbon-14 concentration and so will reduce the opportunity for exchange with plants. Hence one is dealing with a transient, not an equilibrium, situation, and merely computing the fractional increase in the total carbon-14 reservoir caused by adding bomb-produced carbon-14 may not give a good measure of the impact of the bomb-produced carbon-14 on man but would tend to give too low an estimate. Libby states (18), "Bomb tests to date have produced enough carbon-14 so that when it has come to mixing equilibrium it will have increased the amount naturally present in all living matter by one-third of 1 percent"; and, "In the years before equilibrium with the deep ocean is reached—about 500 years—the level will temporarily rest at about a 3 percent increase. \* \* \* This is after the first period of perhaps ten or twenty years before dilution in the top layer of the ocean and with living and dead organic matter occurs, when the increase will be about 20 percent." Finally, he says, "Because the lifetime of radiocarbon is very long—8,000 years on the average—the equilibrium situation is the more significant." For the carbon-14 already produced by bombs, the average dose increment over 8,000 years is about 1.7 times the average dose increment calculated on the assumption of immediate equilibrium.

**Carbon-14 dose to man.** Libby (16) estimates the dose to man from naturally occurring carbon-14 as 1.5 milliroentgens per year. If no further bomb carbon-14 was produced, this dose rate might be as high as 1.8 milliroentgens per year during the next 20 years or so; after that time it would gradually drop off to a new equilibrium value of 1.505 milliroentgens per year. The average dose rate over 8,000 years would be about 1.508 milliroentgens per year, yielding a total dose increment due to bomb-produced carbon-14 of 64 milliroentgens.

These dose estimates suggest that the present bomb-produced carbon-14 hazard to man is not only small but virtually undetectable: a 0.5 percent increase in a dose rate that itself is only 1 percent of the natural background radiation dose to man. Why, then, is bomb-produced carbon-14 possibly a concern? The answer is that genetic mutation rates, and possibly some somatic-effect incidence rates [for example, leukemia (19)], are considered to be linearly proportional to total dose. On this basis, therefore, any increase in the dose to man implies a corresponding increase in the burden of mutations in the population, and possibly an increase in certain somatic effects, such as leukemia.

**Numerical estimation of the genetic effects of bomb-produced carbon 14.** By means of the methods discussed earlier, it is easy to compare the estimated genetic effect of the carbon-14 produced by nuclear detonations to date with the estimated effects of the naturally occurring carbon-14 and the total natural background radiation (Table 4). The natural background radiation of 150 milliroentgens is essentially that estimated in the National Academy report (9). The natural and bomb-produced carbon-14 doses have been discussed above. An average life of carbon-14 of 8000 years and a stable world population of  $2 \times 10^9$  are assumed. The genetic effects estimated for the carbon-14 radiation dose are doubled to take into approximate account the transmutation effect, as discussed earlier. Depending in part upon whether absolute numbers or fractional increases are considered, different persons may place different interpretations upon the figures given in Table 4. Furthermore, individuals differ in their viewpoints regarding the genetic effects in the next few generations as opposed to effects over the next 8,000 years.

Leipunsky (3) has published estimates of the genetic and leukemogenic hazards of nuclear weapons. As noted earlier, he assumed a very high neutron escape per 200 Mev of energy released—a figure that may be high by a factor of 4 to 6 as compared with actual neutron escape from U.S. weapons. Except for the fact that he ignores the transmutation effect of carbon-14, his calculations of the genetic hazards appear to be valid for the doses he assumed, although he made computations for only the gross physical or mental defect category. There also appear to be errors in Leipunsky's calculation of the leukemogenic hazards—a calculation based on the as yet unproved linear relationship between dose and leukemia incidence postulated by Lewis (19). Since leukemia resulting from strontium-90 (the major fission product contributing to the bone dose) would be largely of bone-marrow origin, Leipunsky's use of Lewis' (19) values for probability of leukemia from bone-marrow and lymphatic-system irradiation resulted in estimates twice those obtained when the appropriate value for the probability as given by Lewis is employed. Finally, Leipunsky's calculation of both the bone and gonadal doses may be questioned because of his

assumption that the internal cesium-137 dose is proportional to cumulative, rather than annual, deposition of fallout and by his consideration of cesium-137 as the only contributor of external gamma radiation. Except for these differences in assumptions affecting the estimates of dosages, including assumptions about the number of neutrons escaping to air, we are in general agreement with Leipunsky's calculations.

#### Conclusions

(1) Subject to large uncertainty, the transmutation effect of carbon-14 atoms contained in the genetic material of the human body could lead to about the same number of genetic mutations as the radiation effect from carbon-14.

(2) Genetic damage estimates are subject to large uncertainties and should be used in this light.

(3) Because nuclear weapon detonations have already produced radioactive carbon-14, the number of persons in the world likely to have genetic or other abnormalities from carbon-14 radiation will be increased. Expressed as a fraction, the increase from bomb testing to date is very small, but the total number of persons likely to be affected in the next 8,000 to 10,000 years may not be considered small by some persons.

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CALIFORNIA INSTITUTE OF TECHNOLOGY,  
Pasadena, May 4, 1959.

HON. CHET HOLIFIELD,  
Chairman, Special Subcommittee on Radiation, Joint Committee on Atomic Energy, Congress of the United States, Washington, D.C.

DEAR MR. HOLIFIELD: I hereby submit to the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, U.S. Senate, my report on the

States two articles, for consideration at the hearings of the subcommittee, now going on, on the nature of radioactive fallout and its effects on man, and for inclusion in the printed report of the hearings.

The first of these communications is the paper "Genetic and Somatic Effects of Carbon 14," by Linus Pauling, published in *Science*, November 14, 1958, volume 128, No. 3333, pages 1183-1186.

In this article it is pointed out that the genetic and somatic effects of carbon 14 produced by the testing of nuclear weapons are comparable in respect to the numbers of people affected with the effects of worldwide fallout of fission products from the same tests, although the effects of carbon 14 extend over a longer period of time than those of the fission products. It is also pointed out that a much larger quantity of carbon 14 per megaton is produced by fusion than by fission.

I am sure that there will be some discussion of carbon 14 in the course of your hearings, and I feel that my published article on this subject, which is one of the first in which a serious effort was made to estimate the genetic and somatic effects of this radioactive substance, should be included in the hearings and in the printed account of the hearings.

The second article is "The Effects of Strontium 90 on Mice" by Barclay Kamb and Linus Pauling, published in the proceedings of the National Academy of Sciences of the United States, volume 45, No. 1, pages 64-69, January 1959. (See p. 2347.) In this paper there is given a statistical analysis of data on the effects of strontium 90 injected into mice on life expectancy and on the incidence of tumors of blood and blood-forming tissues. These data have been published by Dr. Miriam P. Finkel. (See p. 2342.) An important part of the paper is the development of general mathematical techniques of statistical analysis of data on the biological effects of strontium 90. The article deals with the important question of whether or not there is a "threshold" in the action of strontium 90 in producing leukemia and bone cancer and in causing decrease in life expectancy. The conclusion is reached that the data obtained by Dr. Finkel do not permit a statistically significant conclusion about the existence or non-existence of a threshold to be reached.

This article has broader use than its application in the discussion of Dr. Finkel's data. The mathematical methods developed in it might be applied in the statistical analysis of data obtained in other experimental investigations bearing on the question of the existence or nonexistence of a threshold for strontium 90. My colleague, Prof. Barclay Kamb, who joins me in asking you to present this article to the subcommittee during its hearings and to include it in the printed account of the hearings, agrees with me in the opinion that the question of a threshold for strontium 90 will surely be discussed at the hearings and in the belief that our published article on the subject is a significant one with respect to this question.

I may take this occasion to state that I have the strong conviction that the mechanism of production of cancer by high-energy radiation, such as that produced by radioactive fallout, is closely similar to that of the production of genetic mutations by this radiation, and that for this reason we are forced to conclude that there is no threshold for the action of strontium 90 in producing leukemia and bone cancer. Genetic mutations are generally believed by scientists to be produced by damage of a molecule of deoxyribonucleic acid in a germ cell. There is now much evidence indicating that in general cancer is caused by molecules of nucleic acid in somatic cells. There is no doubt that molecules of nucleic acid in somatic cells could be damaged by high-energy radiation just about as easily as those in germ cells. This argument leads us to conclude that the production of cancer by high-energy radiation would resemble the production of genetic mutations in not having a threshold, and that accordingly even very small amounts of radiation, to which all human beings are exposed, produce cancer.

I enclose two copies of the paper on "Genetic and Somatic Effects of Carbon-14" and also two copies of the paper on "The Effects of Strontium 90 on Mice."

Also, if your subcommittee should request me to do so, I would be glad to present in person my testimony about these matters and other matters relating to the nature of radioactive fallout and its effects on man.

Sincerely yours,

LINUS PAULING.

Reprinted from *Science*, November 14, 1958, Vol. 128, No. 3333, pages 1183-1186

## Genetic and Somatic Effects of Carbon-14

This by-product of nuclear-weapon testing may do more genetic and somatic damage than has been supposed.

Linus Pauling

In his 1956 paper on radioactive fallout (1) Libby pointed out that neutrons released in the explosions of nuclear weapons react with nitrogen nuclei in the air to make carbon-14, which has a half-life of about 5600 years. In his discussion of bomb-test carbon-14 he said that "Fortunately, this radioactivity is essentially safe because of its long lifetime and the enormous amount of diluting carbon dioxide in the atmosphere." He pointed out that 5.2 tons of neutrons would be needed to "double the feeble natural radioactivity of living matter due to radiocarbon. Such an increase would have no significance from the standpoint of health." He mentioned that, for a given energy release, thermonuclear weapons produce more neutrons than fission weapons, and concluded that "the essential point is that the atmosphere is difficult to activate and the activities produced are safe."

Perhaps because of a feeling of reassurance engendered by these statements, I did not make any calculations of the genetic and somatic effects of the carbon-14 produced in the testing of nuclear weapons until April 1958. I was then surprised to find that these calculations, which form the subject of this article (2), lead to the conclusions that the genetic damage, as measured by the pre-

dicted number of children born with defects caused by the mutations induced by the radioactivity, may be greater for carbon-14 than for the fission products ordinarily classed as world-wide fallout, and that the somatic effects may be of the same order of magnitude.

In his 1956 paper Libby stated that a 20-kiloton weapon, involving fission of 1 kg of plutonium or uranium, would produce 10 g of neutrons, of which 15 percent might reasonably be expected to escape and make carbon-14. The yield of carbon-14 would hence be 1.65 kg per megaton (the maximum would be 7 kg per megaton, if all neutrons were effective).

More information was given in his 27 March 1958 address on radioactive fallout, delivered at the symposium of the Swiss Academy of Medical Sciences in Lausanne and released on that day by the Atomic Energy Commission (3). In this address he said that 1 megaton with fusion and fission weighed as they have actually occurred would generate  $3.2 \times 10^{24}$  atoms of carbon-14, which is 7.4 kg. He pointed out that this estimate is higher than the earlier estimate based on an assumed 15-percent escape efficiency, and said that the new value is based on firmer information.

The old value was for fission alone. If we assume it to be valid, we might conclude that the sevenfold increase to the

new value is to be attributed to a high yield for fusion. For example, if the energy yields for fusion and fission have been equal for past explosions the carbon-14 yield for fusion might be calculated to be 13.8 kg per megaton, about 13 times that given for fission.

On 29 May 1958, after the calculations described in this article had been made, my attention was called by Ben Tucker to the paper "Radioactivity danger from the explosion of clean hydrogen bombs and ordinary atomic bombs," by O. I. Leipunskii, published in the December 1957 issue of the U.S.S.R. journal *Atomic Energy* (4). The values given there agree only very roughly with my values. Leipunskii gives 5.2 kg per megaton as the amount of carbon-14 produced by fission and 33 kg per megaton as the amount produced by fusion. The latter value represents a 96-percent effectiveness of the neutrons calculated to be released in the  $H^2 + H^2$  reaction giving 1 megaton of energy, or a somewhat smaller effectiveness if some of the 12.5-Mev neutrons produce additional neutrons by  $n,2n$  reactions. The Libby value 7.4 kg per megaton for fusion and fission in the ratio of past explosions is 39 percent of 19.1, the Leipunskii value for fission and fusion in 50:50 ratio.)

Libby gives  $10^{24}$  as the best estimate of the number of carbon-14 atoms introduced into the atmosphere (mostly into the stratosphere) by the bomb tests so far, keeping in mind that a substantial amount falls back as calcium carbonate, especially in the case of ground shots over coral. The number  $10^{24}$  atoms (232 kg) corresponds to 31 megatons of bombs. I assume that one-third of the generated carbon-14 is released to the atmosphere, two-thirds falling back as calcium carbonate. This estimate is based upon the statement by Libby (5) in December 1956 that total bomb tests up to the time his paper was written (it was submitted for publication on 17 October 1956) had liberated 30 megatons of fusion products. It is my understanding, from the table of nuclear explosions given in *The Nature of Radioactive Fallout and Its Effects on Man* (6, pp 2063-

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2065), that fission products were first released in large amounts on 1 March 1954, the earlier explosions having been those of small bombs or of fission-fusion bombs with no large third stage. If the testing has continued at the same rate from October 1956 to January 1958 (reference date for the 1958 statement by Libby) as from 1954 to 1956, the value 232 kg of carbon-14 introduced into the atmosphere corresponds to 45 megatons of fission and, with the surmise that the fission-fusion ratio has been 1 to 90 megatons of total tests, and hence to the above estimate that one-third of the carbon-14 becomes atmospheric  $\text{CO}_2$ .

The 232 kg of carbon-14 (Libby's estimate) introduced into the atmosphere by the bomb tests had caused the carbon-14 concentration for atmospheric carbon dioxide in New Zealand to increase to 10 percent over its normal value by 1957 (7). The carbon-14 released into the atmosphere becomes mixed in a few years with the biosphere and the top layer (about 300 feet thick) of the ocean (8, 9). Mixing occurs more slowly with the deep layers of the ocean. Studies by several authors (8, 9) have led to closely similar conclusions about the rates of mixing. We shall make use of a simple model discussed by Arnold and Anderson (9); essentially the same conclusions would be reached with use of any model compatible with the value 600 years for the age of the dissolved carbon in the ocean.

## Two Reservoirs of Carbon

In the simple model of Arnold and Anderson two reservoirs of carbon are considered. Reservoir A consists of the atmosphere (0.13 g of carbon per square centimeter), the land biosphere (0.05 g  $\text{cm}^{-2}$ ), and humus (0.2 g  $\text{cm}^{-2}$ ), totaling  $2.0 \times 10^{16}$  g of carbon, of which 3200 kg is carbon-14. Within this reservoir there is rapid equilibration of carbon-14. Reservoir C is the entire ocean, including the ocean biosphere; it contains  $8.5 \text{ g cm}^{-2}$  ( $44 \times 10^{18}$  g) of carbon, 22 times as much as A.

The equilibrium between A and C can be expressed by a forward rate constant  $k$  and reverse rate constant  $k'$ , with values  $k = 0.035 \text{ yr}^{-1}$  and  $k' = 0.0016 \text{ yr}^{-1}$ , respectively.

Let us consider  $N_0$  atoms of carbon-14 released into A by 1 year's testing at a standard rate, which we assume to be 30 megatons per year, with 222 kg of car-

bon-14 made and 74 kg released into A. The later number ( $N_A$ ) of these atoms in A is given by the equation

$$\frac{dN_A}{dt} = -\lambda N_A + k(N_C - N_A) \quad (1)$$

The solution of this equation is

$$N_A = \frac{k}{k + \lambda} N_C + \frac{k}{k + \lambda} N_0 e^{-(k + \lambda)t}$$

which with insertion of the values of  $k$  and  $k'$  becomes

$$N_A = 0.044 N_C + 0.956 N_0 e^{-0.036 t}$$

So far  $N_0$  has been considered a constant. We replace it by  $N_0 e^{-\lambda t}$  corresponding to the radioactive decay of carbon-14 with mean life 8070 years (half-life 5556 years), to obtain

$$N_A = 0.044 N_C e^{-\lambda t} + 0.956 N_0 e^{-(k + \lambda)t} \quad (2)$$

Hence, the freshly made carbon-14 in reservoir A, which gives it access to the bodies of human beings, can be considered as consisting of a 4.4-percent fraction with mean life 8070 years and a 95.6-percent fraction with mean life 27.5 years (the reciprocal of 0.0364  $\text{yr}^{-1}$ ).

## Genetic Effects at

### Present Population Levels

Let us first evaluate the genetic effect of the carbon-14 from bomb tests on the assumption that the population of the world will remain constant.

James F. Crow, a member of the National Academy of Sciences-National Research Council Committee on Genetic Effects of Atomic Radiation, presented an estimate of the genetic effects of a 0.1-roentgen exposure of the gonads in his testimony before the Special Subcommittee on Radiation of the Joint Congressional Committee on Atomic Energy on 4 June 1957 (6, p. 1021). He estimated that a 0.1-roentgen exposure of the gonads of the present world population would produce gene mutations that would in the course of many generations give rise to the birth of 80,000 children with gross physical or mental defect, 300,000 stillbirths and childhood deaths, and 700,000 embryonic and neonatal deaths. Of these, 8000, 20,000, and 40,000, respectively, were expected to occur in the first generation. In addition, he estimated that there would be produced a larger but unknown number of minor or intangible defects, which might represent the major part of the damage,

because by virtue of their being milder they are less likely to cause the sterility or death of the person who possesses them and therefore are more likely to persist in the population and thus to affect a larger number of persons.

The estimates for the three categories were made in different ways, and the categories are not mutually exclusive. In particular, deaths at about the time of birth are included in both the second and the third category. Crow has told me that in his opinion there is little overlap between the first and the second category.

These estimates must be recognized as highly uncertain. Crow said that they might be 5 times too high or 5 times too low, or more, but that we are better off estimating even very crudely what the numbers involved are than not making any numerical estimates at all. I agree with this statement.

Uncertainty in these estimates does not affect the discussion of relative effects of carbon-14 and fission products given below.

It must be emphasized that, although large numbers are given below as the estimated effects of the testing of nuclear weapons at the recent rate, these numbers are very small in comparison with numbers representing the effects of natural radiation and other mutagenic agents. For example, it is stated in the National Academy of Sciences-National Research Council report that about 2 percent of total live births have tangible defects of simple genetic origin (this is roughly the first category of the three given above). With 75 million births per year, this corresponds to 1.5 million per year with gross physical and mental defect. The estimated effect of continued testing of nuclear weapons at the recent rate is an additional 15,000 per year (including the effect of carbon-14). Hence the bomb tests are expected to produce not more than a 1-percent increase in defective births (or between 0.2 percent and 5 percent, if we use Crow's suggestion about uncertainty in the estimates).

The estimate of the magnitude of the gonad exposure for the average rate of bomb testing for the 5 years preceding 1956, reported by the National Academy of Sciences-National Research Council committee, is 0.1 roentgen in 30 years. Hence 1 year of testing at that rate, it is estimated, will cause about 2700 children with gross physical or mental defect, 10,400 stillbirths and childhood deaths, and 23,000 embryonic and neo-

natal deaths. (This estimate ignores the effects of carbon-14.)

The Twenty-third Semiannual Report of the Atomic Energy Commission contains the statement that bomb testing at the present rate, it can be estimated, will cause between 2500 and 13,000 defective children to be born per year of testing. This statement is in the report of the Advisory Committee on Biology and Medicine. It seems to correspond to the above calculation, with recognition of the uncertainty of the amount of overlap between the first two categories.

The report of the National Academy of Sciences-National Research Council committee contains the sentence "With these understandings, it may be stated that U.S. residents have, on the average, been receiving from fallout over the past five years a dose which, if weapons testing were continued at the same rate, is estimated to produce a total 30-year dose of about one tenth of a roentgen; and since the accuracy involved is probably not better than a factor of 5, one could better say that the 30-year dose from weapons testing if maintained at the past level would probably be larger than 0.02 r and smaller than 0.50 r. The rate of fallout over the past five years has not been uniform. If weapons testing were, in the future, continued at the largest rate which has so far occurred (in 1953 and 1955), then the 30-year fallout dose would be about twice that stated above."

It is accordingly possible that a somewhat larger estimate than 0.1 roentgen in 30 years should be made for the average gonad exposure corresponding to the recent rate of testing of nuclear weapons. Little can be done to make the estimates of the effects of fission products more reliable in the absence of any published detailed discussion of the evidence upon which the estimates of gonad exposure are based.

Now let us consider the genetic effects of carbon-14. The gonad exposure due to natural carbon-14 has been given by Libby (10) as 0.0015 roentgen per year. This dosage was calculated on the basis of the assumptions that the body is 16 percent carbon, the specific activity of carbon is 15 disintegrations per minute per gram, and the mean energy of the beta radiation is 40 percent of the maximum energy, 167 kev.

If we take as the present rate of bomb testing the value 30 megatons per year (fission plus fusion), the initial activity of the carbon-14 from 1 year of bomb tests is 0.0015 roentgen per year multi-

plied by 74/3200, the ratio of the amount of carbon-14 released to reservoir A by the tests to the amount of natural (cosmogenic) produced carbon-14. This initial activity is  $35 \times 10^{-6}$  roentgen per year. Of this amount,  $1.45 \times 10^{-6}$  roentgen is associated with the first term in Eq. 2 and  $33 \times 10^{-6}$  roentgen with the second term. The total gonad exposure is obtained by multiplying these quantities by the corresponding mean lives, 8070 and 27.5 years, respectively, to obtain 0.0018 and 0.0009, respectively, with sum 0.0027 roentgen.

We see that the second term (the non-equilibrium term with respect to mixing with the large ocean reservoir) contributes only about 8 percent as much as the first term in the total effect. On the other hand, it is the more important of the two with respect to the present generation and the next one.

The total gonad exposure due to carbon-14 over the entire life of the isotope (per person now living, world population assumed constant), 0.0127 roentgen, is 4 times that usually assumed for world-wide fallout (0.0033) roentgen, corresponding to 0.1 roentgen in 30 years). The estimated effects of carbon-14 from 1 year of bomb testing, from Crow's numbers, are 12,000 children with gross physical or mental defect, 38,000 stillbirths and childhood deaths, and 90,000 embryonic and neonatal deaths.

## Genetic Effects at

### Predicted Population Levels

Now let us consider the effect of the increase in world population that can be reasonably anticipated. At the present time the world population is growing at a rate such as to double in about 50 years. If we assume that no catastrophe intervenes, this rate may continue for hundreds of years, and the population may then remain essentially constant, with a value for number of births per year 5 times the present value. The number of defective children corresponding to the first term of Eq. 2 would then be multiplied by a factor nearly equal to 5. If the world population were to increase in this way, the carbon-14 from 1 year of testing would cause an estimated total of about 35,000 children with gross physical and mental defect, 170,000 stillbirths and childhood deaths, and 425,000 embryonic and neonatal deaths. On this assumption about world population it is estimated that the bomb tests carried

out so far (estimated total, including 1958, 150 megatons; will cause about 5 times these numbers of defective children and deaths.

Thus we see that the genetic effects of carbon-14 from bomb tests are estimated to be about 4 times as great as those of ordinary world-wide fallout (calculated for the customarily quoted value of gonad exposure) if the world population stays constant, and about 17 times as great if the world population increases as assumed.

There is a simpler way of making the calculation (11). Let us assume that there is very rapid mixing of the carbon-14 released in the bomb tests throughout the entire reservoir, including the depths of the ocean. With this assumption and the other assumptions given above, a straightforward calculation can be carried out, leading to nearly the same numbers.

These predicted effects of carbon-14, which over the period of thousands of years are greater than those of the fission products in the world-wide fallout, may be thought to have little significance because of uncertainty about the nature of the world of the rather distant future. It is accordingly of interest to calculate what the effects of 1 year of testing will be on the next generation.

## Effects of One Year's Tests on the Next Generation

We may consider first the predicted number of seriously defective births in the next generation as a result of the ordinary fallout. From Crow's estimates and the gonad exposure 0.1 roentgen in 30 years, there are 270 children with gross physical or mental defect, 670 stillbirths and childhood deaths, and 1304 embryonic and neonatal deaths.

In calculating the number of seriously defective births expected to occur in the first generation as a result of the presence of added amounts of carbon-14 in the atmosphere we cannot neglect the rate of diffusion of carbon-14 into the depths of the ocean. The 74 kg of carbon-14 liberated into the atmosphere by 1 year of testing at the standard rate causes an initial increase of 2.3 percent of the carbon-14 concentration, the normal burden of the atmosphere, biosphere, humus, and upper part of the ocean being 3200 kg. This calculation agrees roughly with the statement by Libby that "the observed carbon-14 rise

might be as high as 3 percent per year as appears to have been observed." The rate of increase, reported from experiment, for carbon dioxide in the atmosphere is about 2.1 percent per year.

It may be pointed out that the observed rate of increase of carbon-14 in the atmosphere provides some justification of the assumed standard recent rate of testing, 30 megatons of fission plus fusion per year (together with the assumption that one-third of the carbon-14 that is produced is liberated to the atmosphere), as shown by the agreement of the calculated 2.3 percent increase per year and the observed 2.1-percent increase. The same rate of increase in the atmosphere and the same genetic and somatic effects would result from, say, 20 megatons per year with one-half escaping. The calculation of genetic and somatic effects could be based directly on the observed rate of increase of carbon-14 in the atmosphere.

The rate of diffusion of the carbon-14 into the depths of the ocean corresponds to a mean life of 27.5 years in the smaller reservoir. The gonad exposure for natural carbon-14 is 0.0015 roentgen per year and that for an amount 2.3 percent as much is 0.00035 roentgen per year. With a mean life for carbon-14 in the small reservoir of 27.5 years, the total gonad exposure for the first decades after the testing becomes 0.00096 roentgen. With world population at the present level, the estimated numbers in the three categories during the first generation due to carbon-14 from a single year of testing are 80, 200, and 400, respectively. These are smaller than estimates for the ordinary radioactive fallout. It is because of the very long life of carbon-14 that the total effect, throughout the life-times of the isotopes, becomes greater for carbon-14 than for the fission products.

The possibility must be considered of a special mutagenic action of carbon-14: the damage of a deoxyribonucleic acid molecule through the Szilard-Chalmers effect or the chemical effect of conversion to a nitrogen atom when a carbon-14 atom in the molecule undergoes radioactive de-

composition. We assume 50,000 genes per individual, 200,000 carbon atoms per gene,  $5 \times 10^{10}$  future world population up to 30 years of age, and a carbon-14 yield of 74 kg to the atmosphere per year of testing, and calculate 50,000 as the number of mutations by this mechanism per year of testing. This number, presumably an upper limit, is only about 10 percent of the numbers in the three categories expected to result from carbon-14 irradiation, and we conclude that the special mechanism involving carbon-14 atoms in the genes themselves is less important than irradiation in causing genetic damage.

The calculation of predicted somatic effects of bomb-test carbon-14 in comparison with those of fission products can be easily made. With the same assumptions as for the foregoing calculation of the genetic effects, including the assumption of a fivefold increase in world population, it is found that 1 year of testing of nuclear weapons produces carbon-14 irradiation, over the entire life of the radiocarbon, equivalent to the exposure of the present world population to a whole-body dose of 0.061 roentgen. This is much larger than the customarily quoted value of 0.0033 roentgen for whole-body irradiation by fission products from 1 year of testing, and somewhat larger than the estimated exposure of bone marrow and bone tissue by strontium-90 (given as 0.03 and 0.056 roentgen, respectively, per year of testing, as estimated by the Atomic Energy Commission's Advisory Committee on Biology and Medicine, in the *Twenty-third Semiannual Report of the Atomic Energy Commission*, 1958). Hence we calculate that the total number of cases of leukemia and bone cancer expected to be caused by carbon-14 is about equal to the number expected to be caused by fission products, including strontium-90, and that the number of cases of cancer of other sorts expected to result from radiation damage to tissues other than bone marrow and bone tissue is greater for bomb-test carbon-14 than for fission products.

#### Summary

On the basis of information about carbon-14 given by Libby, calculations are made of the predicted genetic and somatic effects of the carbon-14 produced by the testing of nuclear weapons. It is concluded that 1 year of testing (30 megatons of fission plus fusion) is expected to cause in the world (estimated future number of births per year 5 times the present number) an estimated total of about 55,000 children with gross physical or mental defects, 170,000 stillbirths and childhood deaths, and 425,000 embryonic and neonatal deaths. (There is an unknown amount of overlap of these three categories.) These numbers are about 17 times the numbers usually estimated as the probable effects of the fallout fission products from 1 year of testing. In addition, the somatic effects of bomb-test carbon-14 are expected to be about equal to those of fission products, including strontium-90, with respect to leukemia and bone cancer and greater than those of fission products with respect to diseases resulting from radiation damage to tissues other than bone tissue and bone marrow. All of the estimated numbers are subject to great uncertainty; they may be as much as 5 times too high or 5 times too low. The uncertainty in the estimation of the relative effects of carbon-14 and fission products in world-wide fallout is not so great.

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[From the New York Times, Apr. 29, 1958]

PAULING PICTURES NEW BLAST PERIL—SAYS CARBON 14, LONG-LIVED ATOM, IS GREATEST FUTURE THREAT FROM FALLOUT

(By John W. Flinney)

WASHINGTON, April 28.—Dr. Linus C. Pauling, leading biochemist, introduced today a new threat in atomic fallout—a long-lived radioactive atom known as carbon 14.

The Nobel Prize winner, who has taken the lead in arguing the dangers of fallout, said carbon 14 represented a far more serious, long-term menace than all the other radioactive byproducts of an atomic explosion, including the much-publicized strontium 90.

While strontium 90 is a more immediate threat, he warned, over a period of 5 to 10,000 years the danger to the human race from carbon 14 is 200 times greater.

He discussed this development with reporters after a talk at the annual meeting of the National Academy of Sciences.

#### FIVE MILLION DEFECTIVES SEEN

The carbon 14 created in atomic bombs already exploded will cause 5 million genetically defective children in the next 300 generations and millions of cases of bone cancer, leukemia, and other bodily damage, he predicted.

It is an isotope created by the bombardment of the atmosphere's nitrogen by neutrons resulting from either an atomic or hydrogen bomb explosion.

It has generally been dismissed as a fallout threat because of its extremely long life—the isotope has a half-life of about 5,600—and, consequently, the low-level radiation it emits during the prolonged process of radioactive decay.

Dr. Pauling said he had been "shocked" to read in a recent speech by Dr. Willard F. Libby, scientist of the Atomic Energy Commission, how much carbon 14 was created in atomic explosions. Dr. Libby's estimate, he said, was 17 pounds in an explosion having a force of 1 million tons of TNT.

With the nuclear weapons already tested, Dr. Pauling asserted, the earth's content of carbon 14 has been increased 10 percent. He said the substance represented a particular threat because carbon was so widely distributed in animal and plant life and could be found in every tissue of the human body.

Atomic Energy Commission officials conceded that carbon 14 presented an appreciable genetic hazard over a period of several thousand years. They questioned, however, that the danger was as great as portrayed by Dr. Pauling.

One uncertainty, they said, is how much of the substance created in an explosion found its way into the human body.

From the standpoint of somatic or body damage, they expressed doubt that carbon 14 presented too great a threat since only a small amount would be present in any one generation.

A system developed by Dr. Libby has made carbon 14 useful for dating archeological finds. This has no relation to fallout.

Dr. Pauling's scientific paper dealt with "the dependence of longevity of human beings on body weight." He concluded that from the standpoint of life span, there was no danger in being 10 pounds overweight.

While seemingly far removed from the fallout question, the paper was prompted by Dr. Pauling's running debate with Dr. Edward Teller, nuclear physicist, who has argued that fallout is no substantial threat.

The paper was designed to refute a recent statement by Dr. Teller that fallout, as far as shortening life span, was as dangerous to human health as being an ounce overweight.

Dr. Teller's statement was based on the past assumption that an ounce of overweight would shorten the life span by 26 days. Dr. Pauling said his statistical studies showed a shortening by 2.6 minutes.

Dr. Teller was "in error by a factor of 1.440" an "should have said that fallout is 1,440 times as dangerous to human health as being one ounce overweight," Dr. Pauling told his audience.

At the meeting experimental evidence was given supporting the belief that genetic damage caused by radiation was directly proportional to the amount of radiation.

Dr. M. Demerec of the Carnegie Institution of Washington reported that his experiments with bacteria had shown such a direct dose-effect relationship.



A "heretical" theory about the effects of radiation in causing genetic damage was introduced by Dr. W. L. Russell of the Oak Ridge National Laboratory.

Most geneticists believe that the genetic mutation rate will be the same for the same dose of radiation, whether it was received in one big dose or gradually over an extended period.

Dr. Russell said his experiments with mice had brought a "surprising result"—the mutation rate was lower if the radiation dose had been accumulated gradually.

CONGRESS OF THE UNITED STATES,  
JOINT COMMITTEE ON ATOMIC ENERGY,  
May 1, 1958.

Gen. K. E. Fields,  
General Manager, U.S. Atomic Energy Commission,  
Washington, D.C.

DEAR GENERAL FIELDS: I would appreciate it very much if you would have your Division of Biology and Medicine provide the Joint Committee with a statement on the effects of carbon 14, resulting from thermonuclear explosions, on succeeding generations of mankind. In that connection it would appear appropriate to make an analysis of the calculations by Dr. Pauling which were publicly made in the press the other day.

It would also appear appropriate to analyze the statements made in the article by the Russian scientist O. I. Leipunsky which appeared in the December 1957 issue of *Atomnaya Energiya*, a translation of which was transmitted to the Joint Committee by C. L. Dunham, M.D., Director of the AEC Division of Biology and Medicine, in his letter of April 30 to Chairman Durham.

Very truly yours,

CLINTON P. ANDERSON,  
Vice Chairman.

[From the New York Times, May 16, 1958]

LETTERS TO THE TIMES: GENETIC MENACE OF TESTS—VIEWS REGARDING POTENTIAL DAMAGE FROM CARBON 14 REAFFIRMED

*The writer of the following letter won the Nobel Prize in chemistry in 1954. He is head of the chemistry division and director of the Gates and Crellin Laboratory of the California Institute of Technology and a former president of the American Chemical Society.*

To the EDITOR OF THE NEW YORK TIMES:

I have read with interest the letter from Drs. J. Laurence Kulp, Wallace S. Broecker and Arthur R. Schubert in your issue of May 2. In this letter they say that my statement that carbon 14 represents "a far more serious long-term menace than all other radioactive byproducts of an atomic explosion" is incorrect and that carbon 14 will contribute only a minor fraction of the radiation produced by strontium 90 and cesium 137.

In fact it is their statements that are incorrect. When the cumulative dose to the entire population over the total lives of all isotopes is considered, the radiation from the carbon 14 produced by bomb tests is found to be considerably larger than the amount attributed by the Atomic Energy Commission to other isotopes and the number of defective children that can be predicted to be produced by the radiation from carbon 14 is far greater than the number predicted for other isotopes.

DR. LIBBY'S STATEMENT

In his 1956 paper on radioactive fallout Dr. W. F. Libby pointed out that neutrons released in the explosions of nuclear weapons in air react with nitrogen nuclei to make carbon 14; he said that "fortunately this radioactivity is essentially safe because of its long lifetime and the enormous amount of diluting carbon dioxide in the atmosphere."

Perhaps because of a feeling of reassurance engendered by this statement and others by Dr. Libby, I did not make any calculations of the genetic and somatic effects of the carbon 14 produced in the testing of nuclear weapons until last month.

Dr. Libby gave additional information about carbon 14 in his March 27 address in Lausanne, including a statement about the amount of carbon 14 generated per megaton, with fusion and fission weighed as they had actually occurred; this amount is 7.4 kilograms, about seven times the amount that he had reported in 1956 for a pure fission weapon. He states that a considerable part of the carbon 14 (which I estimate as two-thirds) falls back as calcium carbonate; the rest of it enters the reservoir of which the biosphere is a part. At the present time the concentration of carbon 14 in the atmosphere has been increased by the bomb tests to a value of 10 percent greater than its former value. As carbon dioxide dissolves in the ocean, this percentage will ultimately decrease if the bomb tests are discontinued.

#### EFFECT CALCULATED

I shall calculate the effect of carbon 14 on the basis of the following assumptions: The rate of bomb testing is 30 megatons a year. One-third of the generated carbon 14 is released to the atmosphere. There is moderately rapid equilibrium with a large reservoir, including the ocean, with normal content 14,000 kilograms of carbon 14. The mean life of carbon 14 is 8,070 years; the normal amount of carbon 14 in the human body produces a gonad exposure of 0.0015 roentgen a year, as stated by Dr. Libby.

The effect of a single gonad exposure of 0.1 roentgen for a world population equal to that at present is to cause ultimately a total of 380,000 seriously defective children (gross physical or mental defects, stillbirths, childhood deaths) plus 700,000 embryonic and neonatal deaths. This estimate was made by Prof. James F. Crow, a member of the National Academy of Science National Research Council Committee on Genetic Effects of Atomic Radiation, in his testimony before the congressional subcommittee on radiation on June 4, 1957; the population of the world, which has increased by over 1 billion during the last 100 years, will continue to increase and will have an average value during the next 10,000 or 20,000 years such that there will be five times as many children born as at present.

A straightforward calculation based on the above assumptions leads directly to the conclusion that 1 year of testing at the standard rate of 30 megatons a year (two 15-megaton bombs, similar to the one detonated by the United States on March 1, 1954) will ultimately be responsible for the birth of 230,000 seriously defective children and also for 420,000 embryonic and neonatal deaths.

#### ESTIMATE BY AEC

We may compare these numbers with the number caused by the other isotopes. The official estimate given in the 23d semiannual report of the Atomic Energy Commission is 2,500 to 13,000 seriously defective children a year of testing. I think the number may be somewhat higher, but the statement is justified that carbon 14 is a far more serious long-term genetic menace than the other products of atomic explosions.

The bomb tests carried out so far (including 1958, which is starting off as a bad year) can be estimated to correspond roughly to five 30-megaton years. Accordingly we may say that the predicted effect of the carbon 14 released in these bomb tests will be to produce about 1 million seriously defective children and about 2 million embryonic and neonatal deaths, and that the predicted effects of the other isotopes will be somewhat smaller.

As other people have pointed out, these numbers will represent a minute fraction of the total number of seriously defective children and of embryonic and neonatal deaths during coming centuries. But I feel that each human being is important, and that it is well worthwhile to calculate the numbers of individual human beings who will be caused to suffer or to die because of the bomb tests, rather than to talk about "negligible effects," "undetectable increase," "extremely small fraction."

LINUS PAULING.

PASADENA, CALIF., May 8, 1958.

(In response to the Joint Committee's request of May 1, 1958, for comment on Dr. Pauling's calculations, as reported in the press on April 29, the AEC submitted the following statement commenting on Dr. Pauling's letter to the editor of the New York Times, dated May 16, 1958, above.)

ATOMIC ENERGY COMMISSION,  
Washington D.C., August 25, 1958.

HON. CLINTON P. ANDERSON,  
Joint Committee on Atomic Energy,  
Congress of the United States.

DEAR SENATOR ANDERSON: In reply to your letter of May 1, 1958, I enclose (1) a copy of the manuscript of a technical report (Rept. No. WASH 1008) soon to be issued by the Technical Information Services, Oak Ridge, and (2) a short statement commenting on the calculations of Dr. Pauling to which you referred.

The report is entitled "The Biological Hazard to Man of Carbon 14 From Nuclear Weapons Testing." It includes discussions of the possible mutagenic effect of the transmutation of carbon 14 which has been incorporated into the genetic material and of the basis for making numerical estimates of the genetic hazards to man posed by radiation. The report also includes a brief discussion of the Leipunsky paper and an estimate of the genetic effects of the carbon 14 produced to date by weapons testing.

It is our understanding that the Leipunsky paper did not influence the report prepared by the United Nations Scientific Subcommittee on the Effects of Atomic Radiation.

Sincerely yours,

H. S. VANCE, Acting Chairman.

(The article of O. I. Leipunsky will be found on p. 2423.)

COMMENTS PREPARED BY THE DIVISION OF BIOLOGY AND MEDICINE CONCERNING DR. PAULING'S CARBON-14 ESTIMATES IN LETTER MAY 16, 1958, TO EDITOR OF THE NEW YORK TIMES<sup>1</sup>

Pauling made the following assumptions:

- (1) Bomb testing at the rate of 30 megatons per year.
- (2) 7.4 kg carbon-14 produced per megaton.
- (3) 1/3 of the carbon-14 reaches the reservoir of which the biosphere is a part.
- (4) 74,000 kg carbon-14 of natural origin in the reservoir.
- (5) Mean life of 8,070 years.
- (6) Normal carbon-14 content gives 0.0015 r/year to gonads.
- (7) Essentially immediate equilibrium.
- (8) 5 times as many births per year on the average over the next 10,000-20,000 years as now.

The assumptions concerned with the rate of carbon-14 production were based largely on data given by Libby. Except possibly for number 8, all of these assumptions appear reasonable and are probably as good as could be made on the basis of the information available to Pauling. The assumption of 5 times as many births as at present seems questionable. However, it is only necessary to divide Pauling's estimates by 5 to obtain comparable estimates for a stable population of about the present size.

<sup>1</sup> For further comment, see p. 56, vol. I.)

Pauling based his calculations on Crow's estimates given on page 1021 of the Fallout hearings. Assuming a doubling dose of 50r, a stable world population with  $2 \times 10^9$  births per generation and a dose to the gonads of 0.1r per generation (i.e., per 30 years), Crow made the following estimates:

| Kind of damage                          | Total for future generations |
|-----------------------------------------|------------------------------|
| A—Gross physical or mental defect.....  | 80,000                       |
| B—Stillbirths and childhood deaths..... | 300,000                      |
| C—Embryonic and neonatal deaths.....    | 700,000                      |

Pauling's calculations are straightforward and merely consist of adjusting the above estimates to correspond with the total dose increment estimated from the bomb-produced carbon-14 and with the five times greater population which he assumed. The adjusted values for categories A, B, and C are 48,400, 181,500, and 423,500 respectively. Pauling failed to recognize that categories B and C are partially overlapping.

He did not consider the possibility that mutations could perhaps result from the transmutation into nitrogen of carbon-14 incorporated in the genes.

Pauling made the further modification of combining categories A and B into one class of damage which he called "seriously defective children." Thus he obtains his rounded estimates of 230,000 "seriously defective children" and 420,000 embryonic and neonatal deaths resulting from carbon-14 produced by 30 megatons of bomb testing. Pauling then compared these numbers " \* \* \* with the number caused by the other isotopes." He stated: "The official estimate given in the Twenty-third Semi-annual Report of the Atomic Energy Commission is 2,500 to 13,000 seriously defective children a year of testing." Since the estimates given in the 23rd semi-annual report corresponded only to Crow's category A, this comparison was a bit unfair although the more proper comparison of 48,400 versus 2,500 to 13,000 still supports Pauling's conclusion that the estimate of total carbon-14 damage is greater.

As noted earlier, Pauling's assumptions yield an estimate of 48,400 cases of gross physical or mental defects (category A) due to carbon-14 produced by 30 megatons of testing. It is of interest to compare this number with the number expected over the same period on the basis of the normal incidence of such defects. Crow gives two per cent as the normal incidence due to genetic causes and five per cent as the total incidence including both genetic and nongenetic causes. If one assumes 10 billion births per generation as Pauling did, there would be about 2,690 billion births in the next 8,070 years. An estimated five per cent or 134 billion would be born with serious physical or mental defects including about 54 billion due to genetic causes. The estimate of 48,400 due to the bomb-produced carbon-14 is less than one-millionth as great as the number expected from the normal genetic incidence and is 1/2,700,000 of the total expected. As Pauling indicates in his final paragraph, it is a matter of personal opinion whether to conclude that the fractional increase is so small that it may be ignored or whether to consider the absolute number of cases so large as to be of grave concern.

## APPENDIX H

Extracts From "Report of the United Nations Scientific Committee  
on the Effects of Atomic Radiation"—1958

### Chapter III PHYSICAL DATA

#### I. INTRODUCTION

1. In estimating doses to which populations are exposed, the Committee has classified the sources into three categories:

- (a) Natural;
- (b) Man-made (except environmental contamination);
- (c) Environmental contamination.

The relative risks from different radiation sources, in general, increase with the radiation doses from the sources. It is therefore useful to compare the doses from various man-made sources with those from the natural sources to which the human race has always been exposed.

2. In this report, consideration has been given to those sources which are contributing to the population dose at the present time, together with some estimates of future exposure from environmental contamination. In the future, various man-made sources may increase in relative importance; the radioactive waste of atomic industry, nuclear reactor accidents and the use of isotopes in medicine, research and industry may well become problems.

#### II. DOSE ESTIMATES REQUIRED FOR EVALUATION OF BIOLOGICAL RISKS

3. A quantitative estimation of the total deleterious irradiation effects in a general population must be based upon information as to the extent of the likely biological effects as estimated from assumed dose-effect relationships and also upon individual weighting factors appropriate for the deleterious consequences as discussed in chapter II, paragraphs 26 and 27.

4. Only in the case of a linear dose-effect relation with no threshold value of the dose is it relevant to add the dose contributions from various sources. This can be done in the case of genetic injury and, according to one hypothesis, also in the case of a possible induction of leukemia.

5. In order to meet the requirements of subsequent chapters which are concerned with biological consequences, it has been necessary to estimate the following doses:

- (a) For evaluation of genetic injury: the dose to the gonads.
- (b) For evaluation of possible induction of leukemia: the mean marrow dose (averaged overall 1,500 g of active marrow).

For most uniform exposure of the whole body, the listed gonad doses are very close to the mean whole body dose. The significance of partial exposure of the body (as in medical practice) is difficult to evaluate, but a useful index of risk seems to be the significance of each corresponding exposure of marrow as expressed by the mean marrow dose.

6. As the genetic effect of exposure is assumed to be a linear function of gonad dose, it is possible to weight the individual doses directly, the weighting factor being the future number of children to be expected by each individual subsequent to the exposure. A weighted *genetically significant dose* is accordingly defined in chapter II (paragraph 27).

7. According to one hypothesis, the induction of leukemia is also a linear function of dose. The appropriate weighting factor is not known but as a first approximation the various contributions to marrow exposure may be compared without weighting. Another hypothesis assumes a threshold for the induction of leukemia; in this case a *per capita* marrow dose has no meaning but the individual marrow doses become determining factors.

#### III. METHODS OF MEASUREMENT

8. The ultimate purpose of radiological measurements of concern to the Committee is the estimation of tissue dose from natural sources, man-made sources and environmental contamination. In some cases, however, measurements of radioactivity are also of primary concern. It is emphasized that new and improved methods are constantly being developed.

9. It is customary to classify measurements of this nature into categories relating to the method used, i.e. direct or indirect. Direct exposure measurements are those made with ionization chambers or instruments calibrated in terms of air ionization. Indirect methods are those where dose is calculated from activity measurement. The rates of exposure from medical and industrial practice and from terrestrial and cosmic radiation are sufficiently high to allow direct measurement. Exposure rates from other sources are low and the dose must usually be estimated indirectly by activity measurement and subsequent calculation.

10. A survey of the methods of measurements which have been found to be valuable in relation to the work of the Committee is given in annex E.

#### IV. NATURAL SOURCES OF RADIATION

11. Man is exposed to radiations from: (a) external sources, namely cosmic rays and terrestrial radiations from radioactivity in the ground, the air and building construction materials, and (b) internal sources such as the radioisotopes potassium-40 and carbon-14 which are normal body constituents, radium and thorium deposited in bone and radon, thoron and its disintegration products in solution in blood and tissues.

##### *External natural sources*

12. The penetration of the cosmic radiation at sea level is so great that the dose rate of all organs of the human body is practically uniform and equal to the dose rate in air. This dose rate is of the order of 30 mrem per year.

13. The variation of cosmic ray intensity with altitude and geographical location is known. The altitude effect



is the more important: from sea level to 3,000 m the dose rate increases by a factor of approximately 3. At sea level the range of variation with latitude is 14 per cent; at an altitude of 4,000 m it increases to 33 per cent. There are also small longitudinal and temporal variations. Cosmic ray intensity is only slightly reduced even inside massive stone buildings.

14. Radiations from the ground arise from radioactive elements in rocks and soil. The concentrations of these radioactive elements (uranium, thorium and their decay products, and potassium) vary widely with geological conditions and are generally higher in granitic rocks than in sedimentary formations or soil. Areas rich in some of these radioactive elements (e.g. monazite sand areas in Kerala, India and Guarapari, Brazil) show exceptionally high radiation intensities<sup>22</sup>. The radiations from the radioactive elements contained in some building-construction materials (masonry) often more than compensate for the shielding effect of the building, so that indoor exposures are frequently higher than those out of doors.

15. On account of the penetrating character of these radiations, the gonad, osteocyte and marrow doses may be considered to be approximately the same. Taking into account the shielding factors and time spent in buildings, it is estimated that radiations from the ground and from building-construction materials contribute in the range of 50 mrem per year to the gonad dose<sup>23</sup>. This range is representative for the major part of the population in the areas for which values have been reported. In high activity areas, such as those mentioned above, the dose may range up to 830 mrem per year<sup>24</sup>.

16. Radon and thoron diffuse from the earth and building materials and constitute a minor external radiation source from which the gonad dose is approximately 1 mrem per year in normal circumstances. High concentrations of radon and of its decay products have been observed in ill-ventilated rooms of masonry buildings in certain areas. Under these conditions slightly enhanced, but still small, gonad doses may arise.

17. Thus, gonad, osteocyte and marrow doses from all external sources are usually of the order of 75 mrem per year, but may range up to 490 mrem per year with local conditions in many countries, whilst in the high activity areas they may range up to 830 mrem per year<sup>25</sup>.

#### Internal natural sources

18. Some of the normal constituents of the human body are radioactive. The specific activity of potassium-40 is about  $10^{-9}$  curies per gram of natural potassium; carbon-14, formed by interaction of cosmic rays with the air, has an equilibrium concentration of about  $7 \cdot 10^{-12}$  curies per gram of carbon, corresponding to the specific activity of the carbon of the atmospheric carbon dioxide. The specific activity is constant and therefore the dose from these radioactive isotopes is determined solely by the potassium and carbon content of the tissues. Soft tissues of the body receive a dose of about 20 mrem per year from internal potassium-40 and of 1-2 mrem per year from carbon-14. The bone (marrow excluded) contains less potassium than soft tissues, and the osteocyte dose from potassium-40 is of the order of 10 mrem per year; bone doses from carbon-14 are similar to soft tissue doses from the same isotope.

19. Soft tissues receive a dose from radon, thoron and their disintegration products taken in from the atmosphere and dissolved and retained in the tissues; the

dose rate is 2 mrem per year. This rate is substantially increased in areas of high natural radioactivity and in badly ventilated buildings constructed of materials containing radioactive elements. The osteocyte dose from this source is negligible. Radium is taken up from the environment and is deposited together with calcium in bone structure. The average osteocyte dose from radium is in the range of 38 mrem per year, but it may be ten times larger in some geographical areas. With a random distribution of the radium in the bone, the average marrow dose will be 2 to 5 per cent of the osteocyte dose.

20. From the above-mentioned figures, the total soft tissue dose from natural internal sources is computed to be 23 mrem per year, the osteocyte dose is in the range of 50 mrem per year, dependent on the radium content of the bone, and the marrow dose is approximately 15 mrem per year.

#### Summary

21. Estimates of doses which arise from natural sources are given in table I.

TABLE I. ANNUAL DOSES FROM NATURAL RADIATION SOURCES\*

| Source                     | Annual dose       |                       |                    |
|----------------------------|-------------------|-----------------------|--------------------|
|                            | Gonad dose (mrem) | Osteocyte dose (mrem) | Marrow dose (mrem) |
| <b>External</b>            |                   |                       |                    |
| Cosmic rays.....           | 28                | 28                    | 28                 |
| Terrestrial radiation..... | 47                | 47                    | 47                 |
| Atmospheric radiation..... | 2                 | 2                     | 2                  |
| <b>Internal</b>            |                   |                       |                    |
| K-40.....                  | 19                | 11                    | 11                 |
| C-14.....                  | 1.6               | 1.6                   | 1.6                |
| Rn-Th.....                 | 2                 | —                     | 2                  |
| Ra.....                    | —                 | 38                    | 0.5                |
| Approximate totals         | 100               | 130                   | 95                 |

\* The totals in the table are for "normal" natural radiation intensity; in certain areas the values range up to ten times higher than those given.

22. Detailed considerations of natural radiation sources are to be found in annex B, including more complete data for different areas.

#### V. MAN-MADE SOURCES (except environmental contamination)

23. At the present time radiation exposures from man-made sources (excluding environmental contamination) arise principally from:

- Medical uses of X-rays and radioactive materials,
- Industrial and research uses of X-rays and radioactive materials, and
- Other sources such as luminous dials of watches, television sets and shoe-fitting fluoroscopes.

#### Medical uses of X-rays and radioactive materials

24. Medical uses of X-rays and radioactive materials are:

- Diagnostic uses of X-rays,
- Use of X-rays and external radioactive sources for radiotherapy, and
- Use of radioactive isotopes as internal sources for diagnosis and therapy.

This section deals only with the exposure of patients. Occupational exposure from medical uses of X-rays and radioactive materials is treated in paragraphs 34-35.

#### Diagnostic uses of X-rays

25. The diagnostic use of X-rays has been of great value in the development of medicine. The wide use of these methods in some countries and their increasing application in many others make it important to consider any risks that such radiation may entail. Estimations of the contribution to the annual genetically significant dose from diagnostic X-ray procedures have been made for some countries in which, however, the use of X-rays is extensive. In some of these countries this contribution seems to be about equal to that from natural sources. A detailed discussion on the values, which are presented in table II, is given in annex C. It should be noticed that all estimates of the genetically significant dose depend on assumptions as to the average child expectancy of various groups of patients of which little is yet known.

TABLE II. ESTIMATED LEVELS OF GONAD EXPOSURE FROM DIAGNOSTIC X-RAY PROCEDURES

|                                      | Annual genetically significant dose (mrem) |                |
|--------------------------------------|--------------------------------------------|----------------|
|                                      | Estimated minimum                          | Probable value |
| Denmark.....                         | 17                                         |                |
| England and Wales.....               | 23                                         |                |
| France.....                          | 37                                         |                |
| Sweden.....                          |                                            | 38             |
| U.S.A.....                           | 50 ± 30                                    | 150 ± 100      |
| Annual per capita gonad dose (mrem)* |                                            |                |
| Austria.....                         | 16-24                                      |                |
| Japan.....                           | 10-30                                      |                |

\* The per capita gonad dose has been found to differ but little from the genetically significant dose in countries for which both have been estimated.

26. More than 80 per cent of the genetically significant dose from diagnostic X-ray exposure is contributed by six or seven procedures (those involving the region of the lower abdomen and pelvis) during which the gonads are usually in the primary field. However, these procedures constitute only about 10 per cent of all examinations.

27. For countries with an extensive use of X-rays, the average annual marrow dose of the population can be estimated to range beyond 100 mrem per person. This figure is very close to the per capita marrow dose from natural radiation. X-ray examinations of the gastro-intestinal tract and of the chest (including mass chest X-ray surveys) give the highest contributions to the average marrow dose. A comparison between dose-contribution is relevant only if a linear dose-effect relationship can be assumed. The average marrow dose per examination varies within the range 1-1,000 mrem for different types of examinations, and the individual doses may show a large variation around each average. This will mean the existence of some heavily exposed individuals who, in the case of a non-linear dose-effect relationship, may run a much higher risk than is indicated by the dose figures. All figures mentioned above refer to the mean dose in the whole mass of active marrow, of which only a small fraction may actually be exposed. The exposed marrow may in extreme cases receive very high doses, especially in the case of fluoroscopy where the dose-rate in the irradiated marrow may be several rem per minute.

28. The data submitted from several countries indicate that it may be possible to reduce the diagnostic exposure considerably by careful attention to techniques. Valuable precautions are described in the current recom-

mendations of the International Commission on Radiological Protection and are collected and further elaborated in the report of the joint study group of the ICRP/ICRU (See annex C). The annual genetically significant dose that may be achieved with good practice without detriment to diagnostic information has been estimated to be 15 mrem for Sweden.

#### Radiotherapy

29. The contribution from radiotherapy in England and Wales has been estimated to be appreciably less than that from diagnostic procedures but greater than that from any other man-made contribution. In the United States, the annual genetically significant gonad dose from radiotherapy has been estimated at roughly 10 mrem. This estimate is based on what appear to be rather conservative figures for the number of treatments per year contributing to the genetically significant dose. Published data for Australia and Denmark estimate a contribution to the genetically significant dose from radiotherapy of 28 mrem per year and 1 mrem per year respectively.

30. The estimated values are not strictly comparable, since different assumptions have been made in each. In the United States estimate all treatment of malignant conditions was disregarded because:

(a) A high percentage of patients were above the average age of child-bearing, and

(b) For many, the prognosis was bad, so that the chance of subsequent parenthood was small.

In the published estimate for Australia, simplifying assumptions were made as to the area of field treated and the dose delivered in the treatment of malignant, pre-malignant and non-malignant conditions. In addition, it was assumed that a normal child expectancy existed for all surviving patients not assumed to be sterilized by the irradiation. In the Danish survey it was assumed that the patients treated for malignant conditions had one-fifth the child expectancy of normal individuals. In the summary table (table III) the range of values is quoted.

31. In considering induction of somatic injuries, the dose from some treatments, such as those of skin cancer and of various benign conditions, should be included in the population average, since prognosis is relatively good and the patients are not ruled out on the age factor. Hence, it appears that radiotherapy may give a contribution to marrow exposure of higher relative significance than the contribution of the exposure of the gonads. No estimate is given of the average marrow dose from radiotherapy, as was referred to the Committee.

#### Medical uses of radioactive isotopes (internal administration)

32. The principal contributions to the population dose from the medical use of radioisotopes arise from the use of iodine-131 and phosphorus-32, which are most widely employed. While considerable quantities of gold-198 are used, the biological significance of exposure from this source is negligible since gold-198 is generally limited to palliative treatment of incurable conditions. Other radioisotopes are used in very small quantities and almost entirely for diagnostic purposes.

33. Estimates of the average gonad dose resulting from the use of iodine-131 and phosphorus-32 can be based upon information about either treatments or radioisotope shipments, the first approach being more accurate and preferable. From the report of the ICRP/ICRU

joint study group and other information available to the Committee it seems likely that the genetically significant dose is lower than 1 mrem per year, even in the countries for which the highest figures can be expected.

#### Industrial and research uses of X-rays and radioactive materials

##### Occupational exposure

34. Industrial, medical, atomic energy and research workers are subject to radiation exposure resulting from their occupation; they may also inhale or ingest radioactive material. Exposure of atomic energy workers is in all countries estimated to contribute less than 1 mrem per year to the genetically significant dose received by the population. The exposure of medical, industrial and research workers is less accurately known but probably adds at the present time less than 1 mrem to the annual genetically significant dose even in technologically advanced countries.

35. The Committee notes that systematic measurement and recording of the exposures of medical, industrial and research workers is desirable since some individual doses are likely to be relatively high.

##### Other sources of radiation

36. Watches and clocks with radioactively luminous dials give an annual genetically significant dose of about 1 mrem. X-rays from television receivers contribute less than 1 mrem. X-rays from shoe-fitting fluoroscopes contribute still less, as they expose a relatively small number of individuals, but might be an important hazard to the exposed individuals.

##### Summary

37. The doses from the principal man-made sources other than environmental contamination are summarized in table III and are appropriate for countries with an extensive use of these sources.

TABLE III. ANNUAL DOSES FROM MAN-MADE SOURCES OF RADIATION (except environmental contamination)\*

| Source                               | Annual Dose                         |                                     |
|--------------------------------------|-------------------------------------|-------------------------------------|
|                                      | Genetically significant dose (mrem) | Per capita total marrow dose (mrem) |
| <b>Medical exposure of patients)</b> |                                     |                                     |
| (a) Diagnostic.....                  | 20-150                              | Ranges beyond 100                   |
| (b) Therapy.....                     | 1-30                                | No estimate made                    |
| (c) Internal.....                    | Less than 1                         | Less than 10                        |
| <b>Occupational</b>                  | Less than 2                         | 1-3                                 |

\* For countries having an extensive use of the radiation sources listed and reporting data to the Committee.

#### VI. ENVIRONMENTAL CONTAMINATION

38. Radioactive contamination of man's environment occurs as a result of nuclear explosions and may also arise from radioactive waste disposal and accidents involving dispersion of radioactivity. At the present time the radiation doses from these last two sources are negligible, but in the future they might become appreciable.

##### Radioactive fall-out

39. Most of the radioactive isotopes which cause the environmental contamination following nuclear weapon

tests are fission products. There are also some formed by neutron induction and some residual fissionable material.

##### Fall-out mechanisms

40. Fission products injected into the stratosphere constitute a reservoir from which they fall onto the whole of the earth's surface over a period of many years (stratospheric fall-out). Fission products not penetrating into the stratosphere may be transported over long distances in the troposphere by air currents but are deposited on the earth's surface by rainfall and sedimentation over a period of a few months (tropospheric fall-out). Because of the gradual deposition of fall-out from the stratosphere, most of the resulting irradiation of man arises from radioactive isotopes of long half-life such as strontium-90 and caesium-137. In contrast, the earlier deposition of tropospheric fall-out makes it necessary also to consider the doses from radioisotopes of much shorter half-life such as strontium-89, zirconium-95 and ruthenium-103 and 106, iodine-131, barium-140 and cerium-144.

41. Near the test site there is an early deposition of radioisotopes which is influenced by various meteorological and testing conditions and which may involve a special hazard to any individual in this area of immediate local fall-out.

42. Meteorological conditions and the predominant occurrence of nuclear tests in the northern hemisphere cause a non-uniform deposition of the longer-lived isotopes over the globe, as a result of which countries between 30° and 50° North experience a deposition of these about three times as great as the world-wide average. Countries in the southern hemisphere and in the tropical belt have smaller deposits with a maximum between 30° and 50° South, of the order of the world-wide average value<sup>20</sup>. In some countries, tropospheric fall-out increases the deposition of the longer-lived isotopes strontium-90 by a small amount. Local meteorological and climatic factors influence the extent and mode of the deposition in a particular locality.

##### Measured contamination of air and ground by strontium-90 and caesium-137

43. Results of measurements of strontium-90 and caesium-137 concentrations in different materials are given in annex D. These show an average air concentration at ground level of strontium-90 of the order of 10<sup>-10</sup> to 10<sup>-12</sup> Ci/l in 1956-1957<sup>20-21</sup>. Values for strontium-90 deposited on the ground at the middle of 1957 were about 8mc/km<sup>2</sup> in Japan, 8mc/km<sup>2</sup> in the United Kingdom, 4-21mc/km<sup>2</sup> in the United States and 3-12 mc/km<sup>2</sup> in the Soviet Union, in the northern hemisphere, and about 4mc/km<sup>2</sup> in Argentina, in the southern hemisphere. At the middle of 1957 a caesium-137 deposit of about 6mc/km<sup>2</sup> was measured in Japan and Sweden (tables XV, XVI and XVIII annex D).

##### Uptake of radioisotopes

44. Radioisotopes enter the human body by inhalation of airborne material and more particularly by ingestion following (a) uptake by and deposition on vegetation, (b) transfer through animals, (c) contamination of water supplies. In this respect strontium-90, caesium-137 and iodine-131 are of special importance. The particulate nature of fall-out and the occurrence of single particles with an activity higher than the average might result in the intake, by a single individual, of an amount of radioactive material exceeding that cal-

culated on the assumption of uniform distribution of the fall-out deposit. The relative importance of the various modes of intake must, however, be considered in assessing the significance of this.

##### Doses from external sources

45. For the computation of dose from fall-out deposit many factors besides the deposition of radioactive materials should be considered, such as the weathering effect on the deposit, leaching through soil and shielding by buildings. Taking into account the fall-out material deposited up to 1958 and excluding the additional radioactive material to fall from the reservoir existing at that time, gonad doses of the order of 1 to 25 mrem have been computed for a 30-year period. The wide range of these estimates is largely accounted for by regional variations. The computations have been made using a reduction factor of 10 for attenuation and shielding of buildings, and for weathering effects. Values suggested for this factor in reports submitted to the Committee range, however, from 3 to 21. It should be pointed out that the gonad dose from external gamma radiation from fall-out deposit is in most cases small compared with the gonad dose from fall-out radioisotopes taken into the body<sup>20-21</sup>.

##### Doses from internal sources of stratospheric origin

46. Radioactive materials entering the human body deliver a dose closely related to the time during which they are retained by the body. This means that many of the radioisotopes produced in fission do not present internal radiation hazards since they do not enter significantly into metabolic processes. Therefore, attention has been centred on radioisotopes which are potentially hazardous by reason of some or all of the following factors: (1) high fission yield, (2) fairly long physical half-life, (3) efficient transfer through the food-chain to the human diet, (4) high absorption by the body and (5) long biological retention time. Special consideration has been given to elements that concentrate in specific tissues even though they do not have all the characteristics discussed. Using these criteria, the important radioisotopes should be expected to be strontium-90 and caesium-137. Other long-lived radioisotopes are considered relatively unimportant as internal hazards as their incorporation in the body is poor. Iodine-131, although of short half-life, is given consideration because of its selective concentration in the thyroid gland.

47. In addition to fission products and neutron-induced activities, some of the residual fissionable material will also be distributed by meteorological conditions and can be hazardous since it consists of alpha-emitting bone-seekers. However, absorption by the body is so very low that there is at present no evidence of any uptake of these materials in human tissues.

##### Strontium-90 in food-chains

48. Since strontium and calcium are chemically similar, strontium-90 follows calcium through the food-chains from the environment to man and is eventually incorporated with it in bone. It has been found that, in the different steps in this chain, there is some degree of discrimination against strontium. This depends upon differences in the utilization of the two elements in various biological processes<sup>20-21</sup>.

49. Computations on the transfer of strontium-90 from fall-out to human bone are complicated by the possibility that equilibrium conditions have not yet been

reached throughout the chain and also that some of the first steps may be more dependent on fall-out rate than on the accumulated deposit of strontium-90. Dietary habits in different countries also vary considerably. Thus milk is by far the most important contributor of calcium to the human diet in some parts of the world, whereas, in other parts, leaf vegetables and cereals are the most important contributors. It follows that it is difficult to calculate with accuracy the transfer of strontium-90 from soil through the food-chain to human bone but information on concentrations in foods and human tissues is available from direct measurements.

##### Strontium-90 in foodstuffs

50. Concentrations of strontium-90 in various foodstuffs differ for different countries. Expressed in microcuries strontium-90 per gram calcium<sup>22</sup>, the ranges of average concentrations in milk from different locations were in 1955 about 1.9 to 7.2, in 1956 1.2 to 8.8, and in 1957 2.7 to 16. In 1956, white rice in Japan contained 36 to 62 S.U. while frozen vegetables in the United States in 1956-1957 contained about 9 S.U., ranging from 1 to 29 S.U.<sup>20-21</sup>

##### Strontium-90 in man

51. Mean levels of strontium-90 measured in the bones of children under the age of 5 years (excluding stillborn) were, expressed in strontium units, 1.5 (Canada, May 1956 to May 1957) 1.15 (United Kingdom, 1957), 0.67 (United States, July 1956 to June 1957), and 2.3 (USSR, second half of 1957). The range of values is typified by the interquartile values for the United Kingdom measurements, 0.7 to 1.8 S.U., while the data for the United States show an approximate gaussian distribution with a standard deviation of about 40 per cent. The age group of 0 to 5 years represents a population that spent all its life in a contaminated environment where the level of contamination of the diet was increasing. The quoted strontium-90 concentrations contribute an average dose of about 2 to 6 mrem per year to the bone cells (osteocytes) or a mean bone marrow dose of 0.7 to 2 mrem per year. A marrow cell which is almost enclosed by bone would receive a dose which may be equal to that in compact bone. The maximum marrow dose received by these cells could differ by a factor of about 5 from the quoted mean marrow levels.

52. The strontium-90 content in bone of the full-term foetus is found to be less than that in bones of children of under 5 years of age. This is typified by results from the United Kingdom where the mean level for stillborns was about 0.55 S.U. in 1957 (42 samples). The strontium-90 concentration in the latter part of the foetal life is directly correlated with the strontium-90 concentration in the mother's blood and this concentration will increase as the contamination of food increases.<sup>20-21</sup>

##### Caesium-137 in man

53. The contamination of food sources by caesium-137 has been found to be rather more dependent at present on fall-out rate than upon the accumulated deposit. Caesium-137 concentrations are often expressed by the caesium-137/potassium ratio. Some evidence exists, however, that the metabolism and routes of entry into the human body of these two elements are to some degree different and that a biological meaning similar to

\* 1 microcurie strontium-90 per gram calcium is called 1 strontium unit, or 1 S.U.

that of the strontium-90/calcium ratios should not be implied. Because of the short biological half-life of cesium-137 (about 140 days), the level of this isotope in the human body must approach equilibrium with the environment relatively quickly.<sup>54a-55</sup>

54. Measurements of cesium-137 in humans in the north temperate zone showed a range of 25 to 70  $\mu\text{Ci}$  per gram of potassium during 1957, corresponding to a gonad dose of about 1 mrem per year (ranging from about 0.5 to 2 mrem per year). On the assumption that the cesium concentration is the same in the marrow as in other soft tissue, the average marrow dose is computed as about 1 mrem per year.<sup>55a-56</sup>

#### Doses from sources of tropospheric origin

55. Fall-out from the troposphere consists mainly of short-lived isotopes. The dose contributions therefore depend to a great extent on fall-out rate rather than on total deposit. Since the mean residence time in the troposphere is relatively short there would be no further exposure from these isotopes shortly after tests were stopped.

56. Tropospheric fall-out occurs predominantly in the latitudes in which tests are conducted and the zones mostly affected are determined by the predominant weather conditions in those latitudes. Caused mainly by the distribution of test-sites, the world-wide distribution of tropospheric fall-out follows roughly the pattern of the stratospheric fall-out. The doses from tropospheric fall-out, therefore, are likely to vary with geographic location roughly in the same manner as doses from stratospheric fall-out.

#### External sources

57. The tropospheric material has an observed mean residence time of two to four weeks and although it is deposited intermittently during the year, a certain deposit of short-lived activities is built-up and maintained. The reported values indicate a level of short-lived radioactivity maintained at about 50 to 200  $\text{mCi}/\text{km}^2$ . Allowing a factor of 10 for shielding and weathering, this gives annual gonad and mean bone marrow doses of the order of 0.25 to 1 mrem. Locally, even at distances of several thousand kilometres from test-sites, levels of the same order as from the natural radiation background (2 mrem/week), however, have been observed for a few days after tests.<sup>57a</sup>

#### Internal sources

58. The air concentration of fission products at ground level has been reported to be around  $10^{-10}$  c/i during 1957. Assuming that this material has the same composition as the fall-out, the annual doses resulting from inhalation can be computed to be of the order of 0.1 mrem or less, except for a thyroid dose of about 0.6 mrem. If the material is insoluble, an annual lung dose of about 1.5 mrem may be expected.<sup>58a</sup>

59. Dose contributions from short-lived activities can be introduced through food-chains when the food has not been stored for a long time. Storage of food reduces the activity of short-lived isotopes, which makes it very difficult, if not impossible, to give world-wide average annual doses from tropospheric material.

60. Strontium-89/strontium-90 activity ratios in milk have been reported as fluctuating in the range 1 to 25 (Canada, Norway, United Kingdom, United States), the values largely depending on whether the cows were on pasture. The strontium-89 may thus give rise to a bone dose ranging from about 1 to 20 per cent of the

dose from strontium-90. Barium-140, in the amounts that correspond to the mean residence time of the tropospheric fall-out (two to four weeks) gives a dose contribution that is less than 10 per cent of that from strontium-89.<sup>59a-60</sup>

61. Measurement of iodine-131 is of interest because of the selective concentration of iodine by the thyroid gland of man and animals. It is not possible to state a representative thyroid dose. Measurements in the United States for the period of 1955 to 1956 show that, excluding areas immediately adjacent to test-sites, the annual thyroid dose in man averaged about 5 mrem. Doses to gonads and other soft tissue from iodine-131 are negligible.<sup>60a-61</sup>

62. Dose contributions from short-lived activities are dependent on fall-out rate. In cases where the dependence on deposit is dominant, as for strontium-90 in the equilibrium that will eventually be reached if tests continue, contributions from short-lived activities will be negligible.

#### Future doses from stratospheric fall-out

63. Prediction of future levels of stratospheric fall-out requires information on the processes connected with the injection of long-lived radioisotopes into the stratosphere and the chain of events that occur between injection of the radioactive material and its appearance as fall-out on the ground. Available information would allow at most a short-term extrapolation.

64. The extrapolation over a short period is, however, insufficient for evaluation of the biological hazards from stratospheric fall-out. For the purpose of a biological assessment it is necessary to extend the calculation over periods much longer than those considered, and many arbitrary assumptions have to be introduced. This makes the estimated values a matter of speculation; and it is, furthermore, very difficult to give any indication as to the degree of uncertainty. Detailed discussion on the prediction of future fall-out levels for certain hypothetical conditions is given in annex D, paragraphs 94-110.

65. Table IV gives 30- and 70-year doses calculated on the basis of extrapolated values of stratospheric fall-out rate and deposit in hypothetical cases. The figures in the table include the external exposure from the deposit of stratospheric fall-out. Taking into account shielding effects of buildings and weathering effects on the deposit, external contribution from the stratospheric fall-out is expected to contribute about 20 to 40 per cent of the gonad dose.

66. It should be emphasized that the figures for doses from stratospheric fall-out are computed from population weighted world-wide average estimates of fall-out rate and deposit. Therefore, regional dose levels differing by a factor of about one-fifth to two can be expected, depending mainly upon latitude.<sup>65a</sup> In some areas of the world the tropospheric fall-out may tend to raise the upper limit of this range, especially in the vicinity of test sites.

67. For the calculations of future fall-out rates and deposits two assumptions are used: (a) the rate of fall-out of strontium-90 will remain in the future at the constant value observed for the last four years, or (b) the rate of injection of strontium-90 into the stratosphere will remain in the future at a value equal to the mean value for the years 1954 to 1958 inclusive. This second assumption gives a value for the fall-out rate and deposit at equilibrium about a factor of 2 higher than that calculated by using the first assumption.

TABLE IV. ESTIMATED DOSES FROM STRATOSPHERIC FALL-OUT\*  
(Computed from population weighted world-wide average values of stratospheric fall-out rate and deposit\*)

| Weapon tests cease at end of 1958...                                        | Constantly decreasing dose:<br>Maximum for any 70-year period (assumption) |              | Per capita mean marrow dose:<br>Maximum for any 70-year period (assumption) |              | Maximum for any 70-year period (assumption) |              |
|-----------------------------------------------------------------------------|----------------------------------------------------------------------------|--------------|-----------------------------------------------------------------------------|--------------|---------------------------------------------|--------------|
|                                                                             | Assumption A                                                               | Assumption B | Assumption A                                                                | Assumption B | Assumption A                                | Assumption B |
| Weapon tests cease at end of 1958...                                        | 0.010                                                                      | 0.010        | 0.16                                                                        | 0.16         | 0.50                                        | 0.50         |
| Weapon tests continue until equilibrium is reached in about a hundred years | 0.045                                                                      | 0.10         | 1.3                                                                         | 2.8          | 7.5                                         | 17           |
|                                                                             | Estimated percentage of the maximum dose for continued weapon tests        |              | Assumption A                                                                |              | Assumption B                                |              |
| Weapon tests cease                                                          | 22                                                                         | 10           | 13                                                                          | 6            | 16                                          | 16           |
| 1958                                                                        | 45                                                                         | 33           | 34                                                                          | 26           | 26                                          | 26           |
| 1968                                                                        | 63                                                                         | 55           | 48                                                                          | 35           | 35                                          | 35           |
| 1978                                                                        | 72                                                                         | 62           | 52                                                                          | 40           | 40                                          | 40           |
| 1988                                                                        | 100                                                                        | 100          | 100                                                                         | 100          | 100                                         | 100          |

\* The methods used for calculation of these doses are given in paragraphs 91 to 126 of annex D.

\* Regional values may differ by a factor of about 1/5 to 2 from the estimated population weighted world-wide average values because of the latitudinal variation of fall-out rate and deposit. In some areas of the world the tropospheric fall-out may tend to raise the upper limit of this range, especially in the vicinity of test sites.

\* The extent to which these estimates apply to populations of different dietary habits and to those living in areas of differing

soil conditions is discussed in paragraph 99.

\* Assumption A is that the injection rate is such as to maintain a constant fall-out rate of strontium-90 and cesium-137, whereas assumption B is that weapon tests equivalent in release and stratospheric injection of fission products to the whole sequence of weapon tests from the beginning of 1954 to the end of 1958 will be repeated at constant rate. This second assumption will give an equilibrium value for the fall-out rate and deposit approximately a factor of 2 higher than that calculated by using the first assumption.

68. The cesium-137 taken into the human body has been considered to be the main radiation source to the gonads and it has been assumed that the human burden of cesium-137 is a quantity dependent on fall-out rate only. The body burden of cesium-137 resulting from a certain value of fall-out rate has been found to vary by a factor of 2 owing to differences in dietary habits.

69. For the bone-marrow dose calculations, relationships between the bone content of strontium-90 and the accumulated deposit have been used. These relationships, which are discussed in detail in annex D to this report, depend on the soil characteristics and the dietary habits in the areas considered. The diet and soil characteristics used in the computations correspond to available data from the United States, the United Kingdom and from Japan for the two types of main calcium sources mentioned in the table, namely milk and rice. In actual practice populations do not subsist entirely on either milk or rice, and these calculations should, therefore, be accepted as approximations. Large local variations are possible: for example, variations by a factor of about 3 are indicated for the Japanese data, because of variations in soil characteristics. Application of these figures to other countries of apparently similar diets also implies uncertainties.<sup>68a-69</sup>

#### Radioactive waste

70. Another aspect of environmental contamination is related to the disposal of radioactive wastes from atomic energy plants. This includes problems such as the ultimate disposal of fission products from spent fuel elements, the release of low-level wastes from the normal operation of reactors and chemical processing plants, and the possibility of accidents. The Committee has not given any detailed consideration to the technical aspects of these problems, but from information available it is clear that there is no general population hazard from this cause at the present time. The Committee realizes that these problems may become of importance in the future and considers that the release of radioactive wastes should be made a matter of international co-ordination and agreement.

#### VII. SUMMARY AND CONCLUSIONS

71. The sources of radiation to which mankind is

exposed include natural sources, medical, industrial and research uses of radiation, environmental contamination due to nuclear explosions and release of radioactive wastes from atomic energy plants and miscellaneous sources such as luminous dials of watches, television sets and shoe-fitting fluoroscopes. Medical, industrial and research uses of radiation expose only a fraction of the population, whilst natural sources and environmental contamination expose the whole population to a more or less uniform level. Average doses to the population from all these sources are, however, of significance with regard to the genetic effect and possibly with regard to some somatic effects.

72. The exposure from these sources is summarized in table V, which gives the genetically significant dose and the per capita mean marrow dose. The genetically significant dose has been calculated for a 30-year period and the marrow dose for a 70-year period. These figures are relevant to the genetic burden and the possible induction of leukemia respectively. The contribution from occupational exposure is at present small compared to that from the other sources of radiation. Although immense quantities of radioactive materials will be produced in the future use of nuclear reactors, the exposure from this source is at present negligible and could in the future be maintained at very low levels by appropriate procedures.

73. Comments on each of the sections of table V are given in the following paragraphs, together with some qualifications regarding the applicability of the various figures. Under the appropriate headings, indications for future fields of investigation are also outlined.

#### Natural sources

74. Exposure of the human population from natural sources is fairly uniform over the earth and a representative figure is quoted in the table. However, areas in several countries show dose levels considerably in excess of those given in the table. More data are needed concerning exceptionally large local variations of exposure from natural sources. These data can be of value in radiobiological research only if good demographic data for the population in the areas exist.

TABLE V. ESTIMATED DOSE FROM DIFFERENT RADIOACTIVE SOURCES  
(Computed from world-wide averages)

| Source                                                                           | Genetically significant dose:<br>Maximum for any 10-year period (mrem) |               | Per capita mean average dose:<br>Maximum for any 10-year period (mrem) (D100) |               |
|----------------------------------------------------------------------------------|------------------------------------------------------------------------|---------------|-------------------------------------------------------------------------------|---------------|
|                                                                                  | Assumption I                                                           | Assumption II | Assumption I                                                                  | Assumption II |
| Natural sources.....                                                             | 3                                                                      |               | 7                                                                             |               |
| Man-made sources (except environmental contamination and occupational exposure)* | 0.5-5                                                                  |               | Range beyond 7                                                                |               |
| Occupational exposure*                                                           | Less than 0.06                                                         |               | 0.1-0.2                                                                       |               |
| Environmental contamination<br>hypothetical cases)*                              |                                                                        |               |                                                                               |               |
| Weapon tests cease at end of 1958...                                             | 0.010                                                                  |               | 0.16                                                                          | 0.36          |
|                                                                                  | Assumption I                                                           | Assumption II | Assumption I                                                                  | Assumption II |
| Weapon tests continue until equilibrium is reached in about a hundred years*     | 0.060                                                                  | 0.12          | 1.3                                                                           | 2.8           |
|                                                                                  | Assumption I                                                           | Assumption II | Assumption I                                                                  | Assumption II |
|                                                                                  | 17                                                                     |               | 7.5                                                                           | 17            |
|                                                                                  | Assumption I                                                           | Assumption II | Assumption I                                                                  | Assumption II |
| Weapon tests cease                                                               | 17                                                                     | 9             | 13                                                                            | 6             |
| 1958.....                                                                        | 42                                                                     | 33            | 24                                                                            | 16            |
| 1968.....                                                                        | 64                                                                     | 36            | 34                                                                            | 26            |
| 1978.....                                                                        | 79                                                                     | 67            | 42                                                                            | 35            |
| 1988.....                                                                        | 100                                                                    | 100           | 100                                                                           | 100           |

\* For countries having an extensive use of the radiation sources listed and reporting data to the Commission.  
\* Data for certain technologically highly developed countries only.

\* Regional values may differ by a factor of about 1/3 to 2 from the estimated population weighted world-wide average values because of the latitudinal variation of fall-out rate and deposit. In some areas of the world, the tropospheric fall-out may tend to rise the upper limit of this range, especially in the vicinity of test sites.

\* Computed from population weighted world-wide average of tropospheric fall-out rate and deposit.

\* The extent to which these estimates apply to populations of different dietary habits and to those living in areas of differing

#### Man-made sources (except environmental contamination)

75. The doses shown under the heading "man-made sources" in the table result mainly from medical diagnostic X-ray procedures. The figures, which contain large uncertainties, refer to countries in which these procedures are now widely applied, and in these countries increasing use may be largely compensated for by improvements in technique. Although these figures are not at present representative for many countries with less extensive medical facilities, the use of X-rays in these countries can be expected to increase greatly in the next few decades. The diagnostic use of X-rays is an indispensable medical aid, and therefore a continuing exposure to mankind from this source will necessarily be incurred.

76. In addition to the diagnostic X-ray procedures, radiotherapy and the medical use of radioisotopes contribute to the population exposure in certain countries with extensive medical facilities. The *per capita* dose from radiotherapy may amount to 20 per cent of that from diagnostic X-ray procedures. However, the significance of the radiotherapeutic contribution depends on the life expectancy of the patients. The genetically significant dose from the medical use of radioisotopes is less than 1 per cent of that from diagnostic X-ray exposure.

77. As medical practice varies considerably, not only from country to country but also from hospital to hos-

pital within the same country, it is very difficult to state the average practice within a general population. Recommendations with regard to suitable sampling procedures for estimating the genetically significant dose have been given by the ICRP/ICRU Study Group (cf. annex C).

78. It seems likely that the present exposure per examination during diagnostic procedures can be reduced considerably, without detriment to their value, by adopting methods of the type recommended by the International Commission on Radiological Protection. Future technical improvements in X-ray equipment and auxiliary devices may also result in reduced exposure per examination, if their use does not invite more extensive examinations.

79. A reduction in dose might be achieved by a further consideration by the medical profession of the circumstances in which X-ray diagnosis is appropriate. This could be facilitated by statistical information on the importance of each examination class for the reduction of any specified morbidity. Administrative co-ordination between authorities who require that certain examinations be made in the routine health surveillance of whole populations or special groups, such as school-children, students, employees, could well be improved.

80. Whilst much of the foregoing discussion relates to population exposures, it must be noted that high individual doses may be incurred during particular X-ray diagnostic procedures especially where poor techniques are used.

81. Although the occupational exposure is at present of little significance for the whole population, the dose to individuals may involve special exposure problems and should be checked by the complementary techniques of site and personal monitoring.

82. A number of sources of radiation, such as luminous watches, television sets, shoe-fitting machines, contribute to the population dose by an amount of the order of 1 per cent of the total contribution from man-made sources.

#### Environmental contamination

83. The Committee has received extensive information on the strontium-90 and caesium-137 concentrations in soil, plants, animal and human foods and in human beings. However, there are many countries from which no data have been submitted. The information so far received, whilst not sufficiently extensive to give a comprehensive world-wide picture, does enable useful conclusions to be drawn.

84. Levels of strontium-90 and caesium-137 vary with geographical location. In addition, other factors such as agricultural conditions and practices, especially of soil and water management, living and dietary habits and food technology will influence the level of these isotopes in man. Because of these factors, caution is necessary in applying data obtained in one area to an estimation of the contamination of the diet in another area.

85. There are at present no practical methods of preventing the entry of these radioisotopes into the human body once they have been released into the environment.

86. The model used in calculating the doses from environmental contamination as set out in annex D of this

report is able to give valuable information for the near future, but the doses given for the 30-year and 70-year periods in tables IV and V in this chapter involve extrapolations over such an extended period that they must be considered as speculative. The figures in the table are population weighted world-wide averages. Countries between 30° and 50° North experience levels nearly a factor of 2 higher than the population weighted world-wide average, whilst countries in the southern hemisphere and those in the tropical belt experience smaller doses.

87. Adequate knowledge on the altitude and latitude distribution of fission products in the stratosphere and of injection rates is required to decrease our uncertainty in the prediction of future doses from fall-out. A better understanding of fall-out phenomena would be achieved if nations co-ordinated sampling and measurement programmes and exchanged data on methods and results. Biological sampling should be co-ordinated with fall-out sampling procedures.

88. In order to interpret information from biological sampling, it is important to consider data concerning soil conditions and pertinent agricultural procedures, such as fertilizer practices, depth of ploughing, and also food technology. The dietary habits in a given area should determine the nature and scope of the sampling programme.

89. The Committee has given initial consideration, in co-operation with UNESCO, FAO, and WHO, to the potential environmental contamination in relation to the disposal of radioactive wastes from atomic energy plants and considers that this subject should be made a matter of international co-ordination and agreement.

## Chapter V

## SOMATIC EFFECTS OF RADIATION

1. The effects of ionizing radiations on man and animals have been observed for many years. These observations have shown that all mammalian cells are vulnerable to this type of injury; they have also demonstrated that tissues and people can, to a very large extent, recover from radiation injury even after severe damage. The clinical manifestations of radiation injury are the end-result of the biophysical effects and of the biochemical reactions through which radiations produce effects on the molecular and cellular level and of a variety of local and systemic physiological and regulatory factors which determine the course and eventual outcome of any injury to the human body. In analysing the action of radiation on the body, it is necessary to consider the physical factors of exposure as well as the relevant biological factors.

## I. PHYSICAL FACTORS

2. The principal physical factor determining the biological effect of ionizing radiation is the dose, defined in chapter II. If the dose is expressed in rem, the influence of the type of radiation (linear energy transfer) is taken into account. The dose of radiation absorbed in all organs must be known. Furthermore, since there may be important differences between the doses absorbed in various organs or even locally within a single organ, the distribution of dose is an important consideration.

3. In the case of external sources of radiation, such differences may result from the following factors: the radiation beam may be directed at only one part of the body (e.g. the hand). The radiation beam may be attenuated as it passes through the body (e.g. X-rays) or may not even penetrate below the surface (e.g. alpha particles). The radiation (e.g. X-rays) may be absorbed quite differently by tissues of different chemical composition (bone, muscle).

4. The distribution in time of the radiation exposure must also be considered. The same dose may be received: (a) quickly, in one exposure (e.g. 10 minutes); (b) slowly and continuously over an extended period (e.g. 5 years); or (c) fractionally (e.g. 1 single dose each year for 10 years). Extending the over-all exposure time as in (b) and (c) greatly reduces the amount of somatic damage with the exception of those changes where a linear dose-effect relationship may apply. Factors of importance in determining the duration of exposure from a radioactive isotope and its daughter products are their physical half-lives, the type and energy of the radiations emitted, the time of retention and the rate of excretion from the body.

5. In the case of radioactive isotopes that enter the body, the dose distribution is determined by the capacity of the various organs to absorb the isotope from the blood. Certain isotopes such as sodium remain in the fluids of the body and thus travel through the whole body. Other isotopes are taken rapidly from the blood by a particular organ, as in the case of iodine concentration in the thyroid gland, or strontium in bone. In

such instances, the dose of radiation absorbed is largely confined to certain organs. The ability of an organ to absorb a specific isotope from the blood depends on its stage of development and varies from time to time with changes in its metabolic state. For instance, in the early stages of human development, the precursors of bone do not selectively absorb strontium. Later on, however, during bone growth, strontium is rapidly absorbed. Still later, when growth has ceased, the rate of uptake decreases.

## Concept of sensitivity

6. Originally, investigators were struck by the rapid and dramatic morphological changes which they observed in the blood-forming organs, the skin, the intestines and the gonads, and therefore classified these organs as "radiosensitive". The greater doses required to produce equally obvious changes in the blood vessels, the lens and nervous system led to an intermediate classification for these tissues or organs. Finally, muscles and connective tissues were classified as "radio-resistant".

7. In the light of our present knowledge, such a simple classification is no longer adequate, and in some respects may be misleading. There are several major factors that enter into the estimation of sensitivity. In general, the estimate will depend on the nature and functional or metabolic state of the biological system under investigation. More specifically, and perhaps more importantly, however, it will also depend on the particular part of the system investigated and on the sensitivity of the methods employed for this purpose. Thus, an organ examined with the microscope will appear to be more sensitive than when examined with the naked eye. Similarly, an organ examined with the most refined physiological techniques may prove to be much more sensitive than when examined by classical morphological methods. It is apparent that as our method of observation changes, the observed sensitivity of the biological system will also change.

## Relation between dose and effect

8. For the scientific study of radiation effects it is necessary to know quantitatively the relation between magnitude or frequency of biological effects and radiation dose, i.e. the dose-effect relationship. Various relations are theoretically possible; two general types will be mentioned here. First, the effect may be direct proportion to the dose. Thus any dose, no matter how small, will have some effect, although after a small dose the somatic effect may be minute. Secondly, there may be a threshold dose below which no effect occurs. In the case of mice of a typical strain, for example, there is a threshold dose of about 400 rem (whole-body exposure to X-rays) below which practically no acute deaths occur. Above this threshold, the number of deaths increases rapidly with the dose, reaching 100 per cent within two weeks after exposure to twice this dose. It may be assumed that intermediate relations exist, represented by a curved line, showing extremely little effect

at low dose, thus indicating an "apparent" threshold.

9. All studies of the dose-effect relationship are complicated by the unavoidable presence of natural radiations. In man, the annual dose from natural radiations is about 100 mrem. It is assumed that a certain amount of genetic damage (some natural mutations) in man is caused by these radiations. It is conceivable that analogous changes may occur in somatic cells and that such changes, being cumulative with age, may have adverse influences. However, there is at present no evidence for such an assumption. It is conceivable that noxious agents, such as carcinogenic compounds, bacteria, parasites and viruses, in our environment may potentiate the effects of radiations.

10. The interpretation of the dose-effect relationship following multiple exposures is more complex than in the case of a single exposure; such an interpretation must take into account a variety of biological factors, recovery and sensitization, for instance. These factors, which are variable, may act separately or in conjunction with each other. The injury may build up in simple proportion to the exposure or it may not increase because the tissues are able to recover before the next exposure occurs. However, repeated exposures would act to diminish the physiologic reserve of the irradiated tissue, and eventually a state can be reached in which repair no longer balances injury. Moreover, previously irradiated organisms may show modifications in radiosensitivity. However, such modifications have not been sufficiently studied.

11. Although a characteristic dose-effect curve may be associated with each somatic effect, the curve will be subject to certain variations which stem from constitutional differences in the populations of animals or human beings. Other factors which have an influence on radiation reactions are sex and age. For certain effects, infants and children react more quickly and with greater severity than adults. During senescence, resistance to radiation declines. Even within groups of individuals homogeneous in age and sex, individual variations occur as a result of differences in genetic constitution and individual history.

## II. GENERAL PATHOLOGY

12. Analysis of the biological action of radiations on multicellular organisms has shown that the sequence of events generally begins with the local damage at the place of the primary biophysical event. Such damage usually involves cellular and extracellular structures of diverse origin and function, and it may range from the almost imperceptible to the very gross. The former may appear as a transitory change, such as an alteration in the permeability of a membrane or an interruption in the secretory activity of a cell, whereas in the latter case the injury will be quite apparent, as in the case of a radiation burn, for instance.

13. Injury, no matter what its cause, brings into play a number of well-known co-ordinated physiological events that are concerned with defence and repair and with maintenance of the integrity of the organism as a whole. Radiation injury follows this universal biological law of reaction to injury, although radiations can modify these reactions to some extent. It is clear that, without repair, we could not use radiations in the treatment of malignant diseases.

14. It is important to remember that radiations do not produce effects that are specific or novel in character. This is true of the morphological changes as well as of

the functional responses. Many of the former can be produced by a number of other agents and some of the transient functional responses to low levels of radiation have been compared to the non-specific alterations associated with the stress-syndrome which can also be elicited by a variety of agents.

15. Radiation injuries have no pathognomonic features which distinguish them from other injuries, but with experience and with a history of radiation exposure, it is possible to recognize patterns of changes which are fairly distinctive. Just as mutations produced by irradiation do not differ in kind from those which occur spontaneously, in the same way, exposure of somatic cells to ionizing radiations has not created new types of diseases. What has been observed is that the incidence of certain types of diseases has been increased by such exposures.

16. It has been observed that, after acute lethal or sublethal irradiation, mammals become susceptible to infection and, indeed, often die because their natural defence mechanisms have been impaired. These mechanisms are complex, but they are chiefly dependent on three main functions: (a) natural barriers to invading organisms; (b) cellular defence-mechanisms (phagocytosis), and (c) humoral-defence mechanisms (antibodies). All three of these functions may be severely affected by a large single exposure, but the extent of impairment from small doses is not known.

17. Disturbances of immunological mechanisms can be produced by external and internal radiation. In the latter case, disturbances may occur when the cells of the reticulo-endothelial system have incorporated radioactive material. This may inhibit the immunological functions of the cells.

18. Exposure to ionizing radiation can lead to the formation of pathologic metabolic products in the tissues, as is known to occur in some other types of injury, e.g. thermal burns. It is possible that these products may play a part in the origin of a number of secondary radiation effects. There is some evidence for the presence of certain toxic products in blood coming from irradiated organs of experimental animals and in the lymph withdrawn from the thoracic duct of these animals. The chemical nature of these substances, normally bound and inactive within the cell, is not known as yet, but some of them are histamine-like substances.

19. Certain types of radiation injury require months or years to make their appearance. This is true whether or not acute manifestations of injury were observed at the time of exposure. Delayed injuries of this type are frequently the result of metabolic and nutritional disturbances in irradiated organs. When the blood supply of the organ has also been impaired, the disturbances are increased and lead to marked diminution in function accompanied by heightened liability to injury and to tumour formation. Such changes are readily observed in the skin and can occur in any organ that has received a sufficiently high dose, either in one brief exposure or over an extended period of time.

## III. SPECIAL PATHOLOGY

20. Clinical observations on large numbers of human beings and numerous studies on a great variety of experimental animals have provided much valuable information on many types of radiation injury in various organs. In general, these lesions are the result of relatively large doses of the order of 100 r. and greater, delivered to



small parts of the body, but the effects of small doses have also been extensively studied.

#### *The blood-forming organs*

21. The tissues producing the formed elements of the blood (red cells, white cells and platelets) are widely distributed throughout the body; they are found principally in the bone marrow, the lymph nodes, the spleen, the thymus (in children) and in the focal liver. The widespread distribution of these tissues makes it very difficult to irradiate any part of the body without exposing part of this system.

22. The majority of the cells composing the blood-forming organs are known to react promptly and to relatively small single doses of radiation. Of the white cells, the lymphocytes are the most sensitive and their response as measured in the circulating blood is a most sensitive indicator of whole-body exposure to radiation in man. Under special conditions of clinical investigation, a temporary drop in lymphocytes has been reported after a single dose of 250 mrem. After repeated doses of a few roentgens, changes in the morphology of lymphocytes (bilobed) have been reported to be more readily detected than a mere reduction in number. It has been established that the blood-forming organs of children are more sensitive than those of adults.

23. Chronic or repeated exposures at low dose levels will impair production of white cells and red cells, but this impairment may not become apparent or detectable for some years. For these reasons, blood examinations are not as sensitive or as reliable a diagnostic procedure as was previously thought. Radiologists and others who, in the past, have been exposed almost daily for many years to relatively low levels of radiation have shown reduced numbers of white cells (leucopenia) and of red cells (anaemia). Among the delayed effects of radiation exposure of the blood-forming organs, leucopenia is the most serious condition. An increased incidence of the disease has been reported among the following five groups of people exposed to radiations: (1) radiologists; (2) atomic bomb survivors of Hiroshima and Nagasaki; (3) patients with severe arthritis of the spine who were treated with X-rays for this condition; (4) children who had been treated with X-rays in infancy to reduce the size of the thymus gland; and (5) a group of children who were exposed when still in utero during diagnostic X-ray examinations of the mother. In two of these five groups, it has been possible to make estimates of the degree of exposure and to relate them to the incidence of leukemia. These data are discussed in detail in appendix G. Finally, it must be mentioned that leukemia can also be induced in certain species of experimental animals by exposure to radiations. Laboratory mice, which are especially susceptible to one particular type of leukemia, have been intensively studied.

#### *Skin*

24. Of all the organs in the human body, the skin is the most frequently exposed, and it probably has been the most frequently damaged, as all external radiations must pass through it before reaching other structures. Since the discovery of X-rays, therefore, skin changes have been very prominent and they have been very carefully analysed. In fact, for a long time, skin reactions (erythema) served as a quantitative measure of radiation dose in man.

25. Until relatively recently, reactions in the skin have been a severe limiting factor in radiation therapy of

deep-seated cancers, and most of our knowledge concerning the effects on the skin has been obtained from observations of the results of therapeutic irradiation with X-rays. Diagnostic procedures rarely lead to observable changes and then only in the case of prolonged or repeated exposures. Contamination of the skin with radioactive material can also produce severe lesions in the skin if the radiation dose is sufficiently great, as has been observed among Japanese fishermen and inhabitants of the Marshall Islands exposed to immediate and local fall-out in 1954.

26. Depending on the size of the field irradiated and on the dose absorbed, changes can be observed ranging from transient erythema, changes in pigmentation, and temporary loss of hair to severe necrosis and ulceration. Among the early radiologists, chronic radiation dermatitis of the hands and face was a common condition, and cancer often occurred in the damaged skin. This was the form of radiation-induced tumours first to be described in man.

#### *Gastro-intestinal tract*

27. The gastro-intestinal tract is relatively easily affected by radiations, and radiologists have learned to exercise particular care when administering radiation to the abdomen. Changes can range from interference with physiological functions such as intestinal motility and secretion of digestive juices to denudation and ulceration of the mucosal lining. Relatively large doses of radiation can cause transient and even permanent depression or cessation of acid and pepsin secretion in the stomach, for instance. Ulcerations produced by radiation may lead to local infection and bacteraemia. These are often produced by bacteria that normally live in the intact intestinal tract without causing harm. Injury by irradiation can thus adversely affect the delicate balance that exists in nature between host and parasite. Denudation may also result in intractable loss of body fluid through the impaired intestinal mucosa. The dose levels required to produce these serious effects have a high threshold. This type of injury to the small and large intestines plays an important and often crucial role in the outcome of the acute radiation syndrome which will be described later.

28. The passage of ingested radioactive materials through the intestinal tract might produce similar injury, especially when such material is insoluble and when it remains for prolonged periods in certain portions of the intestinal tract where for physiological reasons it moves slowly and in concentrated form, as it would do in the colon. No such injury has been described in human beings, but experiments with animals have shown that such lesions can be produced by feeding very large amounts of insoluble radioactive materials.

#### *Nervous system*

29. In the past, when morphological criteria were used almost exclusively for the classification of organs according to their radiosensitivity, the central and peripheral nervous system were regarded as belonging to the more resistant organs. While it is still generally true that considerable doses are required to produce morphological alterations in nervous tissue, it has become apparent in recent years that functional changes can be elicited with much smaller and often very low doses and that such changes may be of great significance.

30. Among these changes one may mention: decrease in excitability, the induction of an imbalance between

the processes of excitation and inhibition, and changes in conditioned reflexes. Modifications of the electroencephalogram have been described at very low doses. Changes of a transitory character are seen in cases of whole-body exposure to doses of several tens of roentgens. Irradiation of animals with 300 to 400 r produces changes in the electroencephalogram of about one week's duration. In cases of exposure to 800-900 r, changes start immediately after irradiation and persist up to the time of death.

#### *Bone*

31. Many lesions of bone have been described in human beings and experimental animals following exposure to radiations from external and internal sources. Damage has ranged from temporary inhibitions of bone growth in children and young animals with relatively small doses (of the order of 100 r) to bone necrosis and fractures following exposure in radiotherapy to doses greater than 1000 r. It is important to emphasize that the growing bones of children and young animals are much more vulnerable than those of mature and older individuals. Skeletal development in childhood can be arrested temporarily by moderate doses. The majority of the bone abnormalities reported has resulted either from large doses used in radiotherapy or from deposits of radioactive materials such as radium and mesothorium in bone. With both types of exposure, malignant tumours have been observed to develop either in bone itself or in structures adjacent to bone. Bone-seeking radioactive materials such as radio-strontium are at present incorporated at greater concentrations in the growing bones of children than in the bones of adults. Such deposition is likely to occur in the areas of most active bone growth (epiphyses). Studies of bones following single or multiple doses of radio-strontium in experimental animals have shown that severe lesions and tumours are most likely to arise in these particular areas.

#### *Gonads*

32. The ovaries and testes are more sensitive than many other organs to damage by radiation. Temporary changes in fertility can be produced, in either sex, by single exposures (30 r in the male and 300 r in the female) or through the cumulative effects of repeated exposures of a few roentgens. Eggs and sperm during development are more susceptible to damage than when mature. The minimal sterilizing dose is less for men than for women. Functional changes in the gonads as a result of exposure to small doses can be observed more readily in women by irregularities or temporary suppression of ovulation and menstruation. Temporary sterility as evidenced by suppression of menstruation may last from a month to a year or so, depending on the dose.

33. In the mouse, chronic irradiation with multiple doses is more effective in producing abnormalities such as changes in the oestrous cycle than is a single exposure. Under chronic irradiation with gamma rays and fast neutrons, fertility of male mice is affected earlier than female fertility; these changes preceded other deviations from normal. Neutrons are more effective in producing changes in the gonads than X or gamma rays. Various types of benign and malignant tumours have been observed in the ovaries of mice following single and repeated exposures to external irradiation. Such tumours are the result not only of the local action of the radiations on the ovaries but also of hormonal disturbances created in the animal as a whole.

#### *Vascular system*

34. Functional and morphological abnormalities in blood and lymphatic vessels have been observed in many irradiated organs, ranging from transient changes in permeability to necrosis and rupture with haemorrhage into the extra-vascular spaces. Changes in the vascular and lymphatic system play an important part in the pathogenesis of many acute and delayed types of radiation damage, as for example in the skin. Erythema of the skin is primarily due to changes in blood vessels, and chronic skin lesions are usually accompanied by prominent vascular abnormalities such as dilated or completely obliterated blood and lymphatic channels. Lesions in blood vessels are likely to produce impairment of arterial and venous blood flow through the affected parts of an organ. Thus they can cause secondary metabolic changes due to diminished blood supply.

#### *Eyes*

35. Acute conjunctivitis and keratitis have been observed following exposure with relatively large doses of a few hundred r. The sensitivity of the retina can be used as a detecting procedure of the effect of radiation upon the human body. However, apart from the retina, perhaps the lens has proved to be the most sensitive part of the eye. Lens opacities (cataracts) have been reported to occur following whole-body and partial body irradiation in man and in experimental animals. Cataracts are a characteristically late effect of radiation. In man, the minimal single dose required for cataract production is estimated to be near 200 rad of X and gamma rays. By a single exposure to radiations from atomic bomb explosions, cataract cases have been reported to be one of the late effects. Neutrons are more effective in inducing cataracts, and several such instances have been observed among physicists in recent years. Cataracts have also been observed in experimental animals (dogs) several years after the administration of radio-strontium.

#### *Lungs*

36. When heavily irradiated, the lungs show slowly developing, progressive changes which have been known as radiation pneumonitis. The rich vascular system of the lungs is susceptible to radiation injury, and delayed changes have been observed in blood vessels. Fibrosis and cancer of the lung have been described in miners of radioactive ores, but many other factors have undoubtedly played an important part in the production of these diseases. However, radiation from radon and its decay products deposited in the lungs of miners undoubtedly augmented the effects of other noxious agents. Radiation pneumonitis and cancer of the lung have been produced in experimental animals by inhalation of radioactive materials such as plutonium and cerium.

#### *Endocrine organs*

37. Functional disturbances of organs with internal secretion have not received as much attention as those of other organs. However, the role of the adrenal cortex in the "alarm-reaction" and in the "stress-syndrome" has been investigated with regard to injury by radiation, and it has been established that radiation can produce certain non-specific effects which are mediated through the adrenal gland (lymphopenia, for instance) and that they are identical with those produced by other "stress" agents. This emphasizes the non-specific character of some effects of radiation. Effects of this type can be obtained with a few hundred roentgens of X-rays, and it is possible that other endocrine processes also con-

cerned with regulatory functions in the body can likewise be affected by such doses. These are matters which require much further investigation.

38. Of all the glands with internal secretion, the thyroid gland is the one that has been studied most thoroughly in man, especially in connexion with radioactive iodine, which is selectively concentrated in this organ. The effects of radiation from radioactive iodine upon the thyroid gland in hyperthyroidism have been of great benefit in the treatment of this disease. Corollary studies have also thrown much light on the early functional effects that radiation may have on this organ and on the morphological alterations that follow later, including the complete destruction of the gland. Endocrinological studies have demonstrated that it is relatively easy to disturb certain sensitive hormonal equilibria existing in the body.

#### Embryonic development

39. Radiation has long been known to be harmful to embryos. Malformations have been observed in children who had been exposed to X-rays or other ionizing radiations while they were developing in the uterus. Our knowledge of these effects is based on what happens after accidental exposure of human embryos coupled with extensive experiments with laboratory mammals. In rats and mice, 200 r of conventional X-rays (250 kv) given to the pregnant mother will selectively destroy specific primitive cells in the embryo at certain stages; this will interfere with subsequent developmental processes. The kind of malformation which results depends upon the phase of embryological development going on at the time of irradiation. In the laboratory it is possible to produce virtually at will a whole series of malformations of the nervous system, skeleton, eye and other organs by properly timing the radiation. In general, a critical period exists for the induction of any particular malformation.

40. The dose of radiation is also an important determinant because some developmental processes are more sensitive than others to disturbances produced by radiation. After low doses (25 to 50 r) only certain abnormalities may occur at given stages, whereas 400 r is so damaging that the embryo usually becomes extremely malformed or it may even be killed at once. In general, the malformative processes that result from radiation of developing mammals can be explained by embryologic principles worked out for other vertebrates.

41. Although human data on the results of exposure of embryo and foetus are meagre and fragmentary, there are sufficient experimental quantitative data to provide a guide for avoiding clinical hazards. The lowest dose of conventional X-rays (250 kv) that will produce visible destruction of embryonic cells in such animals is 30 r and doses of 25 r are capable of causing deviations of skeletal development in mice with certain predisposing genetic backgrounds. In laboratory mammals some of the grossest malformations follow radiation given in the earliest somite stages, or period of early organogenesis but some tissues continue to be highly susceptible to radiation injury throughout intra-uterine life and into the newborn period. For example, the retina of the eye and the brain are particularly vulnerable to malformation. If one makes inferences about man from the results of experimental work on animals in an attempt to assess the risk to the foetus, it can be stated that parts of the human brain are probably susceptible to considerable injury until the last months of gestation and that loss of single developing neurons is possible well into early infant life. Among the children who were exposed in

utero to radiations from atomic bombs, some cases of microcephaly with mental retardation have been observed.

42. It has been demonstrated in experimental animals that soluble radioactive materials when ingested by the mother can be transferred through the placenta to the embryo and growing foetus. Radio-strontium and other substances which may pass through the placental barrier can become fixed in the skeleton or in other organs and produce damage. In the very early stages of embryogenesis, radiation exposure of this type can involve all cells of the growing embryo and resemble whole-body exposure, whereas in later stages of development it will resemble partial body exposure through fixation of material in specific organs.

#### Whole body irradiation: single dose

##### Acute radiation syndrome

43. Clinical studies on people injured by exposure to nuclear radiations from explosions of nuclear weapons and from similar exposures in laboratory accidents have added much to our knowledge of the acute and subacute effects of whole-body radiation in human beings and below the lethal range. The median lethal dose for man is considered to be approximately 300-500 rem. This dose will produce an acute illness, fatal within thirty to sixty days to 50 per cent of the people thus exposed. A few additional people will die after this period. The following is a synopsis of the most important clinical symptoms and of the course of the illness following such an exposure.

44. The earliest symptoms are nausea and vomiting and sometimes diarrhoea; these may appear within an hour after exposure and can last as long as two days. They are accompanied by a feeling of great prostration and fatigue, by hyper-excitability of reflexes and other symptoms attributable to disturbances of the somatic and autonomic nervous system. This first phase, after an exposure to about 400 rem, is followed by a period of subjective well-being, although tissue-damage progresses. Characteristic changes in the white blood cells begin very early; usually they are already present on the first day. An early and rapid fall occurs in the lymphocytes. The granulocytes, after a transient initial increase, also rapidly fall below normal levels. In the fatally injured, all types of white blood cells continue to decrease to extremely low levels. A similar, though less severe and somewhat delayed, fall will be seen in the red blood cells, causing progressive anaemia. There is a tendency to bleeding. This is due to a reduction in the number of platelets, as well as to an increased permeability of blood vessels. Anaemia and leucopenia may be severe at death.

45. At the height of the illness, usually during the second and third week, the fully developed radiation syndrome is characterized by a sustained high fever and extreme exhaustion; there is loss of weight, reddening of the skin (erythema) and loss of hair and there are haemorrhages in the skin, and ulceration of the mouth, throat and intestines. Loss of protective function of the mucosa of the mouth and intestinal tract combined with severe impairment of white blood cell production and of other immunological functions make irradiated individuals susceptible to infections from bacteria normally residing in the individual and usually harmless. Infections of this kind have frequently been the cause of death.

46. It is apparent that initial injury leads to complex chains of events involving practically all organs of the body and may seriously interfere with the balanced in-

terplay between them (homeostasis). Apart from cellular damage, general reactions of the vascular and nervous systems, marked alterations in fluid and electrolyte balance and other metabolic changes play an important and often decisive role in the pathogenesis of this illness.

47. Survivors of injury of this magnitude recover slowly and require a prolonged period of convalescence. Disturbances in the blood-forming organs and in the gonads are the last to disappear and some of the changes in the bone marrow and in the circulating white cells may persist for many months. The patterns of recovery from massive radiation injury of this kind clearly demonstrate that radiation, in addition to producing damage, temporarily inhibits the mechanisms of repair. Interference with reaction to injury is an important factor and its significance may be equal to that of the primary sensitivity of cells.

48. When the dose of a single whole-body exposure is reduced, illness of the type described above is correspondingly less severe and fewer symptoms are observed. It has been suggested that, with a dose of 100 rem, not more than 15 per cent of those exposed would be affected and that illness would be of short duration and comparatively mild. At low dose levels (between 25 and 50 rem) significant findings may be restricted almost entirely to the blood; these will be difficult to detect without special methods.

#### Possible delayed effects

49. It is a peculiar and striking characteristic of radiation injury that although apparent recovery occurs among survivors after exposure to a large single dose of about 400 rem, certain delayed effects may be observed in the years following exposure and recovery. Late changes have now been observed in survivors of a large dose of radiation to the whole body and they include the following: loss of hair, changes in texture and pigmentation of hair, cataracts, impaired spermiogenesis, anaemia and leucopenia and leukemia. It has been said that there is also, in man, a non-specific increase in the mortality rate (shortening of the normal life-span through diseases other than leukemia) but there is as yet no definite evidence for this from studies of atomic bomb survivors in Japan or of comparable groups.

50. Whole-body irradiation may, by randomly producing non-specific tissue changes, adversely influence all these disorders which commonly affect human beings and which ordinarily increase with age.

#### Shortening of the life span

51. All the major delayed effects discussed above will tend to diminish the average life-span. In addition, radiation may have the effect of accelerating the sequence of changes which constitute the "normal" process of ageing. Experiments on animals have demonstrated that whole-body exposure to doses that cause no early deaths and relatively few acute symptoms can, nevertheless, shorten the average life-span, and it is possible that the same may be true for man, although specific human evidence of this point is difficult to obtain. Observations in the United States on radiologists and others using X-rays, during the past twenty years or so, have thus far established an increased incidence of leukemia in this population, and have suggested further that there may be an increased total rate from other "non-specific" causes. Preliminary results of a survey of radiologists in the United Kingdom, however, show no evidence of shortening of life-span in this group as compared with

other medical groups and control populations. The data from man and from laboratory experimentation relating to shortening and lengthening of the life-span are dealt with in annex G.

#### Cancer

52. Within a decade following the discovery of X-rays it became apparent that exposure to radiation carried with it the risk of malignant disease. The first evidence was that of cancer of the skin developing in severe radiation lesions of persons exposed occupationally or in the course of treatment. It has since been found that radiations of various types, external and internal, have induced or help to induce tumours in the blood-forming organs (leukemia), the skin and subcutaneous tissue, the skeleton (sarcoma of bone in radium poisoning), the lung (cancer of the lung in miners of radioactive ores), the thyroid and liver, for instance. Parallel experiments with animals have emphasized the general susceptibility of most tissues of the higher species to cancer induced by radiation.

53. In common with ultra violet rays and with a great variety of chemical agents known to produce cancer, exposure to ionizing radiation is followed by a long induction period before the appearances of malignant growths. In man, the induction period for cancer is often of ten to twenty years duration and it may be even longer. For leukemia the induction period appears to be shorter, and the disease more commonly develops between five and ten years after a single irradiation. It is impossible to estimate the induction time of tumours which occur "spontaneously" in man since their causes are unknown; but the common increase in cancer incidence during later life may indicate that long induction periods are characteristic for human tumours.

54. This induction period is characterized by general tissue changes as outlined earlier, such as destruction of cells followed by compensatory proliferation of new cells and deterioration in the nourishment of tissue due to defects in its blood supply. In the course of these changes, a general derangement occurs in the architecture of the affected tissue. Although the majority of radiation-induced tumours have originated in tissues so altered, the reasons for the increased frequency of cancer in such situations are unknown. Clinical experience suggests that malignant tumours are an infrequent and not an invariable or inevitable result of severe radiation exposure.

55. In certain cases, it has been shown that tumour induction occurs through the mediation of specific physiological or endocrine responses of the whole organism, rather than by specific radiation action on the cell. Such mechanisms are responsible for the induction by irradiation of tumours of the ovary and pituitary in mice. As another example, it has been shown that unirradiated thymic cells introduced into an irradiated host may become the origin of malignant tumours. Such indirect physiological mechanisms have not been demonstrated in man, but it is possible that they exist.

56. Clinical and experimental evidence show that where the total body is irradiated, leukemia is the most probable end-result among the various forms of malignant disease. Leukemia has been the predominant finding among the groups of radiologists studied. Although the relatively soft X-rays to which these men were presumably largely exposed produce more ionization in some calcium-rich areas than in the soft tissues, no increase in bone tumour incidence has been noted.

57. When the skeleton is selectively irradiated by radioelements such as radium, an increase in bone tumours is a prominent result. This is borne out by clinical studies of many persons who, twenty-five to thirty-five years ago, accidentally ingested radium in the process of painting watch dials or received it orally or by injection during inappropriate medical treatment. Cases are recorded in which tumours have arisen in patients who, after twenty or more years, retained between one-half and one microcurie of radium in the whole skeleton, implying an original intake of about one hundred times that amount; this delivered a total average dose to bones of about 2000 rads. Since most of this radiation was delivered by alpha particles, the average dose in rads would be considerably higher. However, some patients with a total radium burden of more than 10 microcuries after more than twenty years have not developed tumours although such individuals invariably show a sequence of destructive and proliferative changes in bone similar to those observed at the sites of origin of malignant tumours induced by radiation.

58. From experiments with animals it is clear that other radioelements which are deposited in the skeleton, e.g. plutonium, strontium-89 and -90 and various rare earth elements can likewise produce bone tumours and other tissue changes which have been observed in radium poisoning in man. While no such cases are recorded in human beings, this may be attributed to the fact that there have been no comparable human exposures to these radioelements. Experimental data suggest that bone tumour incidence can adequately be approximated on the basis of the dose in rems to the osteocytes. Experiments with mice suggest that ten microcuries of strontium-90 in the skeleton are equivalent in carcinogenic effect to not more than one microcurie of radium. In the one series of animal experiments which was designed to determine the dose-effect relationship for radiostrontium and bone tumour, the relationship appeared to be sigmoid; however, there is as yet no critical discrimination between interpretations in terms of a sigmoid, a linear, or a strictly threshold relationship.

59. Since tumours induced by radiations in man and various animals have arisen almost exclusively in damaged tissue, and since experiments have shown that there are levels of radiation below which no increase in the normal "biological background" of tumour incidence can be detected, it has been believed that there is a minimum (threshold) dose of radiation causing the induction of tumours. Such thresholds vary from organ to organ and with the age of the organism. Owing to limitations in experimental methods, including the lapse of time before tumours appear after application of cancer-inducing agents and owing to the "biological background" of spontaneous tumours, and the physical background radiation, the possibility remains that there may not be a true threshold. The situation would then be analogous to that obtaining in the case of genetic changes.

60. In accordance with the latter concept, it has been suggested that the tumour may have its origin through a mutational change in a single somatic cell; or alternatively, that the somatic mutation may be one of the events leading to tumour development. In its simplest form, the somatic mutation theory would postulate that each increment of radiation above the natural background would carry with it a proportional probability of tumour development (linear response). An upper estimate of the effect of radiation in causing tumours of bone can be obtained by the following consideration. If it were assumed that 10 per cent of all primary bone

tumours were attributable to a natural radiation level of 9 rem per 70-year human life-time, and if it were assumed further that the natural frequency of these tumours is between 5 and 10 cases per million individuals per year, and that the increment from added radiation is a linear function of the response and that there is no threshold, then the increment from an addition of one rem per 70 years would be one-ninetieth of the natural incidence. Thus, in 70 years to an assumed 350 to 700 cases per million of population, an additional 4-8 cases would be added. This may be taken as the worst case; if a threshold exists for the induction of bone tumours which is higher than the assumed total radiation, then the increment would be zero. More complex mechanisms of cancer formation would be expected to lead to intermediate values.

61. In attempting similar predictions in the case of leukemia, it also seems reasonable to assume that not all leukemia is due to natural radiation, since there are other known causes in the environment and since human observations at high irradiation doses indicate a lower slope to the dose-incidence curve. Assuming that the increased incidence per rem would be 1.5 per 1 million per year for the rest of the lives of the exposed individuals, and considering the two limiting mechanisms as discussed in the preceding paragraph, we can derive the number of cases added to the natural incidence by 1 rem per 70 years (for a population of mean age 35) as  $1.5 \times 35$ , or 52 induced cases per million persons per 70 years (that is about 150,000 cases per 70 years in a world population of 3 thousand million), in the upper limiting case, and zero in the lower limiting case. The upper value would represent an increment to the natural leukemia incidence which is estimated at 1,400 to 3,500 per million per 70 years (or within the limits of four and ten million in the total population of the world). These are theoretical computations, and it is difficult to estimate the relative importance of radiation and other environmental factors in tumour induction in man.

#### IV. SUMMARY AND CONCLUSIONS

62. A large body of knowledge has accumulated during the last sixty years on the somatic effects of ionizing radiations on man and animals. This knowledge has come from numerous observations on human beings and from extensive experimentation with laboratory animals. In both cases, the effects of external and internal radiation have been studied and, although many of these effects are far from being understood in all details, our knowledge is sufficient to provide a general picture of the events that occur after human beings and animals have been exposed to ionizing radiations of all kinds. In general, the effects following exposure to relatively large doses are well known, whereas the effects of small doses are not understood nearly as well.

63. All types of ionizing radiations produce similar biological effects; these are usually not distinguishable from other pathological conditions. Some radiations, such as neutrons and alpha rays, are more efficient in producing certain types of somatic effects. Physical factors of exposure such as dose, dose rates and dose distribution are as important in determining the nature and extent of the biological effects as are the age and sex of the individual exposed and the part of the body that has suffered exposure. Radioactive isotopes produce harmful effects in those organs in which they are selectively retained. The extent of these effects depends on the physical characteristics of the isotopes, such as the half-life, and the type and energy of the radiations

emitted, as well as on the time of retention in a particular organ and the sensitivity of that particular organ to radiation injury. Absorption of measurable quantities of radioactive materials in human beings and animals has been demonstrated in recent years. Strontium-90, having a half-life of 28 years and being deposited selectively in bone, may be cited as an example to which particular attention must be given.

64. Exposure to relatively large doses of external or internal irradiation produces a variety of characteristic and well-known somatic effects which may occur either immediately or with a delay of a few days to several years. Certain organs, such as the blood-forming organs, the skin and the gonads, are particularly vulnerable to injury by ionizing radiations. Many of the acute effects, such as erythema of the skin and radiation sickness following whole-body exposure, have characteristic threshold doses. Similar thresholds exist for acute blood and bone disorders following ingestion of large amounts of radium and other radioactive materials.

65. The tissues of the embryo and foetus are among the most sensitive to radiation. Malformations and other pathological conditions have been observed following exposure of pregnant women to accidental and therapeutic irradiation and to diagnostic procedures, e.g. pelvimetry. Experimental work has demonstrated that radioactive materials, such as strontium and other soluble radionuclides circulating in the blood of the mother, can be absorbed and deposited in foetal organs such as the skeleton, where they may produce lesions.

66. As the dose of radiation is reduced below the amounts giving rise to acute functional or morphological alterations, the reactions of the organism become more difficult to detect immediately and the effects may be progressively delayed in time. Thresholds are not easily revealed under these conditions of exposure; in fact, for some of the most delayed phenomena, it is uncertain whether they exist.

67. It is a very characteristic feature of radiation injury that delayed reactions may occur many months or years following exposure. The morphological and functional alterations which occur during the long periods of latency are poorly understood. It has been shown that even after such periods acute manifestations of somatic effects may develop. Among the late effects, leukemia, bone cancer and other malignant changes are worthy of mention. It has been demonstrated that whole-body exposure can shorten the average life span of experimental animals, and it is possible that the same may be true for man.

68. Small doses of radiation given repeatedly can have a cumulative effect in those cases in which the processes of recovery and compensation are limited. It is not known whether sensitization occurs. The existence of adaptation in the broad biological sense of the term has not been proven.

69. In view of the present tendency of the levels of ionizing radiations to increase gradually, as a result of various influences, and on account of the life span of man, it is felt that along with measurements of these levels there should be continuing research on all aspects of the somatic effects of radiation. To ensure a thorough examination of all relevant factors, the Committee points out the importance of:

(a) Demographic studies of populations living in areas that differ in natural radiation levels with reference to effects perhaps attributable to these levels or to other environmental variables which might produce similar effects;

(b) Systematic studies, on a wide scale, of groups of persons who have received radiation for medical purposes;

(c) Continued and expanded experimental work on a wide range of experimental organisms regarding the late somatic effects of small amounts of external and internal radiation with particular emphasis on dose-effect relationships;

(d) The development of methods to serve as sensitive indicators of damage produced by exposure to small amounts of radiation;

(e) Expanded clinical and experimental studies on the nature of cancer and leukemia in connexion with radiation exposure, and on the basic cellular biological problems which may have bearing upon this;

(f) Increased opportunities for exchange of experience among experts engaged in all of these fields of research.

70. It can be anticipated that research in all of these fields will greatly benefit mankind. This will come about not only through a better understanding of the effects of ionizing radiations, but also through increased knowledge of malignant diseases and of the aging process. At the present time, due to the fact that threshold doses for the delayed somatic effects of radiation are not exactly known, it must be recognized that the exposure of human populations to increasing levels of ionizing radiations may cause considerable and widespread somatic damage.



## Chapter VI

## GENETIC EFFECTS OF RADIATION

1. The inherited characteristics of man distinguish him from other species and in part determine the nature of each one of us. They have been accumulated over many generations. Experimental work on many organisms has shown that ionizing radiation can cause mutations, which are permanent, and for the most part deleterious, changes in the inherited characters. It therefore cannot be doubted that exposure of the germ cells of human beings to such radiations will occasionally cause similar changes and so, over many generations, affect individual descendants in populations yet unborn and never themselves exposed.

2. While some hazards are implicit in almost all technological advances, it must be remembered that inherited changes are an inescapable consequence of the irradiation of human populations, and that they affect at random persons who can seldom, if ever, be individually identified. They therefore pose ethical and legal problems which should be of special concern to Governments. This chapter is concerned both with mutation, especially in man, and with the consequences that can be expected from an increase in this process brought about by small general increases in the radiation exposure of human populations. Certain technical terms employed have already been described (chapter II, paragraphs 35-38).

## 1. MUTATION

## General

3. Some facts about mutation have been so widely confirmed by experiments in other organisms that one can have every confidence in applying them to mutation in man as well:

(a) Mutations, once completed, are irreparable. The altered or mutant genes can be changed only by further mutational processes.

(b) Mutations arise at random in this sense: they are not brought about by that particular aspect of the environment toward which the mutant organism will subsequently show an altered response.

(c) The great majority of observed effects of mutations are harmful. The combinations of genes naturally present in the individuals of a species have been selected during very many generations; any random change has, therefore, little chance to be of immediate benefit.

4. Mutations may be roughly classified according to whether they are structural changes involving whole regions of the chromosomes, or whether they are so-called point mutations which apparently involve only single genes.<sup>10</sup> The main problem for man is the effect of irradiation upon the cells of the germ-line from which eggs and sperm are later produced. In experimental studies of animals, gross chromosomal changes are more rarely observed among offspring conceived long after such irradiations than are point mutations; they are also comparatively rare at low doses. Hence, the mutations which are transmitted to future generations are principally the apparent gene mutations—point mutations and those minor re-arrangements and losses that behave like

them.<sup>11</sup> The effects of these small changes range from trivial variation or slight detriment to disturbances having serious effects on reproduction or even survival.

## Natural mutations

5. By natural mutations are meant those which result from conditions beyond our control in normal life, such as natural sources of radiation, thermal agitation and chemical processes within cells. Experimental studies of natural mutations in a wide range of organisms from the unicellular forms to the higher plants, insects and mammals, have indicated that mutation at any one specific gene locus is a very rare event.<sup>12</sup> There is, however, a considerable variation in rates of mutation between various loci as well as between various organisms.<sup>13-15</sup> The estimates of frequencies of appearance of new mutant genes for the mouse and for the fruit fly *Drosophila* mostly range between  $10^{-6}$  and  $10^{-8}$  per locus per tested gamete but, because natural mutation is a rare event, they are subject to large sampling errors and perhaps to some bias in respect of the group for which estimates are available. Frequencies as low as  $10^{-9}$  per locus per cell have been observed in bacteria. In man, test matings cannot be employed to associate a given mutation with a specific locus and special methods, either direct or indirect, must be used to analyze the available material.

6. The direct method<sup>16</sup> is restricted to the study of mutations to dominant genes, that is, to genes which are manifested in heterozygotes, and in a modified form to the study of mutations of genes located upon the chromosomes which determine sex. It is based upon direct counts of the number of sporadic and inherited cases of the condition under investigation. For single clinical entities the estimated frequencies of appearance of new dominant mutant genes mostly range between  $4 \times 10^{-6}$  and  $40 \times 10^{-6}$  per gamete. These values are supported by calculations using the indirect approach. It must, however, be remembered that a single clinical entity may be affected by mutation of any one of many genes.

7. The mutation rates for clinical entities due to recessive genes cannot be estimated by direct counting, but can nonetheless be calculated by an indirect method.<sup>17</sup> This is based upon the hypothesis that there is in the population under study a genetic equilibrium at which as many new forms of genes are produced by mutations as are eliminated by subsequent failures of reproduction. An attempt is then made to estimate this last number. However, a possible slight advantage or disadvantage in heterozygotes may grossly affect the figures, which for this and other reasons are very uncertain indeed.<sup>18</sup> To improve the accuracy of the estimates more information is needed about such selective pressures.

## Radiation-induced mutations

8. All the kinds of ionizing radiations which have been tested experimentally upon living organisms are able to induce mutations which are transmissible to the progeny, if energy is absorbed in the cells of the germ line.

9. It is of basic importance for any discussion of the genetic effects of radiation to establish the relationship between frequency of induced mutation and dose, and especially whether this relationship is linear at the lower dose levels. The Committee emphasizes that there is at present no known threshold of radiation exposure below which genetic damage does not occur. The experimental foundation for a linear dose relationship is fairly well established at moderate doses but is increasingly meagre at lower doses, terminating in one experiment upon *Drosophila* sperm at 25 rad.<sup>19</sup> Experiments already planned or under way in the United Kingdom and in the United States will together test linearity over the range of doses from 37.5 to 600 rad for spermatogonial irradiation of the mouse.<sup>20</sup> However, the range from 5 rad to 25 rad is of primary concern in discussing human hazards. If methods can be found in any organism to test linearity in the above range of doses, especially for gonial irradiation, this test should be carried out. In the meantime, it is prudent to assume at least as much hazard as is implied by a linear relation between mutation and gonad dose, as has been done in the present report.

10. In organisms other than man it has been confirmed that the mutational effect of a given dose is independent of its rate of delivery over a wide range. Moreover, it has been shown that there is no recovery from mutational damage with time in the mouse for periods up to two years after irradiation. The range of times investigated experimentally does not extend nearly as far as the breeding period of some thirty years involved in the chronic irradiation of human populations. Nevertheless, in the absence of evidence to the contrary, the Committee accepts the conclusion that the mutational effects of small doses of radiation delivered to the cells of the human germ line over long periods of time are cumulative. Hence, any irradiation of whole populations must be considered as having genetic consequences.

11. In a number of organisms there is good reason to believe that the radiation-induced mutational event is not completed at the moment of irradiation, but through subsequent physiological processes which may occupy some tens of minutes or even a period of hours. Aside from possible prevention beforehand, the opportunity to effect repair may therefore exist for a limited period after irradiation.<sup>21-23</sup> The Committee considers that investigations directed towards the understanding and the possible eventual establishment of such opportunities should be actively pursued and supported.

12. The balance of evidence at present available suggests that mutations induced by ionizing radiations are in general similar in kind and effect to those of natural origin.<sup>24</sup> In the present report it has therefore been assumed that this is so. Nevertheless, the Committee recognizes that further research is needed before we can be sure that radiation-induced mutations are not sometimes different qualitatively from those of spontaneous origin, and possibly more severe in their effects.<sup>25,26</sup>

13. It will be seen below that, in order to estimate the hazards which arise from the irradiation of human populations, it is convenient to speak of the dose which would produce in a generation as many additional mutations as already occur naturally, called the "doubling dose."<sup>27</sup> Particularly in view of the current acceptance of a linear relationship between dose and frequency of induced mutation, the Committee accepts the validity and practical usefulness of the concept of a representative doubling dose; that is, it accepts that a mean value properly

averaged over a large class of human genes, in so far as it can be estimated, can be taken as a representative figure for the large classes of genes which together determine broad categories of damage in populations.<sup>28</sup>

14. Any estimate in man of induced mutation rates of individual genes requires extremely difficult studies of very large numbers.<sup>29-31</sup> In fact, completed surveys of the progeny of irradiated parents have failed to demonstrate unequivocal changes, or increases in any clinical entities investigated.<sup>32-34</sup> This very failure provides some reason to suppose that the representative doubling dose for human genes does not lie below 10 rad.<sup>35</sup> However, in these surveys, small changes are rather consistently observed to occur<sup>36-38</sup> in the directions expected to result from increased mutation rates. Taken together, these observed marginal changes do seem to establish the occurrence of phenomena expected to result from increased mutation; moreover, it seems somewhat unlikely that they would have been observed if the representative doubling dose for human genes exceeded 100 rad. The Committee therefore accepts as reasonably probable that the representative doubling dose for human genes lies in the range 10 to 100 rad, but for purposes of calculation the geometric mean (about 30 rad) is a convenient figure.<sup>39</sup> The representative doubling dose for human gene mutations cannot in any event lie below about 3 rad, the magnitude of the genetically significant dose delivered in most areas by natural sources of radiation.<sup>40</sup>

15. Any further narrowing of the limits upon the quantitative relations between dose and mutation in man, here expressed through the representative doubling dose, can come only from comparative surveys of the offspring of special irradiated and control groups. The phenomenon which comes closest to being established is a shift in the sex ratio at birth among the progeny of irradiated parents.<sup>41</sup> To clarify this phenomenon and its interpretation, experiments on animals, especially mammals, are urgently needed in parallel with the continuation and extension of surveys relevant to radiation induced genetic injury to man.

16. There is another approach to expressing the overall quantitative relation between radiation exposure and induced mutation in man. It is to ask the question: what total number of mutations is produced by a given exposure of a set of human genes to radiation? Because no direct observations of radiation-induced mutations in man have been made, an answer to this question can only be estimated by the very uncertain procedure of analogy with other species.<sup>42</sup>

## 11. ESTIMATES OF THE EFFECTS OF IRRADIATION

17. It would be desirable to estimate the genetic effects of exposure to radiation in terms of "social consequences". However, such consequences are so diverse in their effects on the individual, on his family and on the community as to be impossible to express numerically. It is possible, however, to measure a number of components, the most satisfactory of which is, at present, the number of people more or less seriously affected by hereditary defects. An alternative measure, more directly related to the total mutation rate, can be expressed in terms of reductions in the capacities of individuals to survive and reproduce.<sup>43</sup>

18. Even complete knowledge of the dose-mutation relations in man would not suffice to make useful estimates of the social consequences (in the sense of the preceding paragraph) resulting from a given exposure

of a population to radiation. Indeed, such estimates cannot be made with any given degree of completeness before the science of human genetics is equally complete. In the present state of knowledge, the Committee has chosen to approach the problem by inquiring successively as to: (a) the magnitude of the social consequences now laid upon human populations by unfavourable genes; (b) the proportion of this due to continually occurring gene mutation; and (c) the increase in gene mutation rates, expressed as a fraction of the natural rates, that can be expected from a given addition to the natural radiation exposure. Under certain assumptions these quantities may be multiplied together to yield a measure of the social burden resulting from a given population exposure.<sup>194</sup> These assumptions are:<sup>195</sup>

(i) That the part of the present genetic social burden due to recurrent mutation is related to the present natural rate of occurrence of mutations, through a balance between production and elimination of unfavourable mutant genes. In fact, the current rate of elimination of such genes must, through their present number and distribution, be related in a complex manner to the history of mutation and elimination in the population.

(ii) That the future environment will be sufficiently similar to the present one for the manifestation of the mutation to be generally the same then as now; in particular, that the relationship between the social consequences and the elimination of the mutant gene will not be significantly affected.

(iii) That the gene mutations brought about by irradiation are qualitatively the same as those of natural origin.

The Committee considers that assumptions (i) and (ii) are reasonable and accepts (iii) as an approximation.

### III. THE SOCIAL BURDEN CONFERRED UPON POPULATIONS BY THE PRESENCE OF UNFAVOURABLE GENES, AND THE EFFECTS OF INCREASED EXPOSURE TO RADIATION

19. One of the tasks of human genetics is to extend our knowledge of the part played by genetic factors in health and disease. This task is largely achieved by highly specialized examinations of affected individuals and their families and by studies of the children of closely related parents, of twins, and of whole populations. All research in this wide field is highly relevant to the problems discussed in the present report.

#### Genetic morbidity due to specific traits<sup>196-200</sup>

20. It is estimated that about 4 per cent of liveborn infants suffer or will suffer from detectable genetic traits of importance. However, it is only under certain conditions that the relationship between changes in mutation rate and changes in trait frequencies can be predicted. Specifically, it must be known that the trait frequency is largely determined by a balance between mutation and selection against the trait concerned; in general, this condition can be satisfied only for traits determined by simple genetic mechanisms, and usually by single mutant genes. In the liveborn, the total frequency of traits thought to satisfy both these criteria is probably not more than 1 per cent of all live births, including some traits whose effects are small.<sup>201</sup> Most of the mutant genes concerned are dominant, although some are recessive.

21. In addition to these traits, there is a considerable number, affecting about 1 per cent of all live births,<sup>202</sup> genetically determined by mechanisms which are by no

means clear. In some, the environment of the embryo in the uterus appears to be of importance in determining whether they are expressed and there is some evidence to suggest that many genes modifying the process in a complex manner are involved. The cleft palate syndromes constitute a good example of this class. Such traits are concentrated in families, but seldom to any extent explainable by genetic theory based upon any simple mechanism.

22. The remaining 2 per cent fall into two groups of unequal size.<sup>203</sup> Those of the smaller group do appear in families in the proportions to be expected from a simple theory of recessive gene transmission, but the over-all frequency of appearance, taken in association with extreme negative selection due to the severity of the traits, is too high to be explained entirely by a balance between mutation and selection—that is, unless mutation rates are postulated which are many times greater than those estimated either for dominant mutations in man or for genes studied experimentally in animals. An excellent example is fibrocystic disease of the pancreas. It may be noted here that many estimates of mutation rates to recessive genes would be very high if they were to be calculated on the assumption of a balance between mutation and selection against the traits concerned. Those of the larger group are illnesses, individually common and severe, which have been attributed by some to simple mutants modified in some way in their expression, but for which the extent and manner of genetic influence is uncertain and hard to determine. The best examples of this class are diabetes mellitus and schizophrenia. If the observed high frequencies of such traits are assumed to be due to a balance of mutation with selection, it is necessary to postulate mutation rates which seem quite unreasonably high; this is true especially if some degree of expression of the trait is common in heterozygotes.

23. Only in respect of the strictly limited category of traits first mentioned above (those determined by single genes), is it possible to predict with any assurance the effect of a given increment in the mutation rate.<sup>204</sup> For all the other traits mentioned, any increment in mutation would eventually be reflected in some equal or lesser increment of trait frequency.<sup>205</sup> Thus, a category of traits affecting some 1 per cent of all live births would be expected eventually to increase in direct proportion with any change in mutation rate maintained over sufficiently long periods. The remaining classes of traits discussed above, affecting some 3 per cent of all live births, would also be expected to increase but this increase would be less than proportional to the change in mutation rate, although the precise extent of it cannot at present be estimated. A permanent doubling of the mutation rate might therefore result eventually in an increase in the present 4 per cent of live births affected by something more than 1 per cent and less than 4 per cent; that is, the proportion affected would rise to between 5 per cent and 8 per cent.

24. The total number of individuals who will ultimately be affected by a given small increase of the mutation rate during just one generation is also calculable: it is equal to the extra number who would be affected in every generation under conditions of equilibrium with a mutation rate permanently increased to the same extent. However, the affected individuals making up this total number would be distributed in an unknown manner over many generations subsequent to that in which the temporary increase of mutation rate occurred.

25. These considerations do not take into account the effects of mutation on the so-called "biometrical" char-

acters considered in paragraph 27 and the succeeding paragraphs; moreover, they disregard the existence of a larger class of mutations to genes with relatively small effects known to occur in experimentally irradiated organisms. Such mutant genes, having individually less adverse effects upon survival and reproduction, would be expected to spread to more members of a population than those considered here, and might indeed constitute the major element in the over-all social consequences of a prolonged increase in mutation rate.

26. On the preceding basis, a simple calculation of the numbers of affected individuals can be made<sup>206</sup> for a steady population of 1 million persons per generation and for each rad of continuous genetically significant exposure per generation. After reaching equilibrium (i.e. after many generations), the number of individual defects attributable to this one rad per generation would probably lie between 100 and 4,000 in each generation of a million persons, i.e. an increase in the number of affected persons of between 0.01 per cent and 0.40 per cent of the population. If the one rad dose were applied only once, to a single generation, a total number of individuals with defects between 100 and 4,000 would be expected, but they would occur spread out in an unknown manner over many subsequent generations. Much of the genetic damage occasioned by mutation takes a considerable time to appear in the form of affected individuals. If it is supposed that the world's population will be stabilized at  $5 \times 10^8$  in the interim before current mutation is so expressed, and that the world population below the mean age of breeding is then about  $2.5 \times 10^8$ , the preceding figures become respectively 250,000 and 10 million in each generation after equilibrium is reached, and 250,000 and 10 million total, but spread out in an unknown manner over a long period subsequent to the irradiation. These calculations would apply to each rad from any source of irradiation affecting the whole population of the earth.

#### Biometrical characters<sup>207-210</sup>

27. Some human characteristics show a type of genetically controlled variation somewhat different from the all-or-none control by specific genes so far considered in this report. These characters can generally be measured in quantitative terms, and are therefore termed *biometrical*. They are determined by genes just like those previously discussed except that their effects are so small, or related to each other and to the environment in such a complex manner, that the effects of individual genes cannot be distinguished, and can only be studied collectively by statistical methods. Consequently, little is known experimentally of their mutations or other behaviour. Yet they are known to exert considerable effects on such important characters as life-span, birth-weight, stature and intelligence. Both the average value and the extent of variations of such characters in a population may be influenced by its genetic constitution; and changes in both must be considered in relation to reproductive fitness as well as to their social consequences.

28. There are two questions of basic knowledge that are largely unanswered: (a) the extent to which the population average is determined by recurrent mutation rather than solely by a balance between selective forces,<sup>211, 212</sup> and (b) the fraction of the genetic component of variation that is due to recurrent mutation.<sup>213-215</sup> The possibility cannot be excluded that for some characters the mutation rate is the primary factor in determining the average and the variability of the population. On the other hand, since influences such as environmental

changes and possible over-all survival and reproductive advantage of heterozygotes may be decisive, the mutation rate may be comparatively unimportant. It must be borne in mind that a rather small number of genes, each maintained at a high frequency by a balance between different selective forces, may well have as large an influence on the mean and variability of the population as would a much larger number of genes each maintained at a lower frequency by a balance between recurrent mutation and selection.

#### Intelligence<sup>216, 217</sup>

29. Intelligence is the character of greatest human concern. It is a biometrical character in so far as it is measured by the standard intelligence quotient. An increased mutation rate among the genes ordinarily determining the genetic variability of the intelligence quotient would tend to increase that variability. This would theoretically lead to an increase in the numbers of persons with high and with low intelligence quotients, although not necessarily equally. At the same time, by analogy with genes whose effects are large enough to be individually detectable and which are commonly found to interfere in a destructive manner with the biological structures or mechanisms primarily affected by them, it would be expected that new mutations would, in general, be such as to diminish the average intelligence quotient. Thus the most probable effect of an increased mutation rate would be to lower the average intelligence quotient, although there is not sufficient experimental basis for any judgement as to the amount of any such lowering.

#### Life span<sup>218, 219</sup>

30. Correlations between relatives and studies of twins strongly suggest a considerable degree of genetic control over the life-span in man, so that mutation would be expected to have some effect upon it. A shortening of the life-span has been observed in the immediate offspring of male mice irradiated with fast neutrons. It is imperative that these studies be continued and extended, for until human data are available we must rely on results from experiments on animals. However, man and mouse are sufficiently different for quantitative extrapolation between the two species to be particularly uncertain. By analogy with the results on mice, a decrease in life-span in subsequent generations would be expected following an increase in mutation rate, but the amount of any such decrease is very uncertain. It should be understood that some of the factors that reduce life-span are the specific genetic diseases and abnormalities discussed earlier.

#### General fertility<sup>220, 221</sup>

31. With appropriate corrections for changes in population size, each unfavourable gene that arises by mutation in a population will be balanced by the elimination in a subsequent generation of a copy descended from it; otherwise the frequency of the mutant gene in the population would increase cumulatively. The means by which these eliminations are brought about is the reduced effective fertility of individuals. This can be thought of as a reduction in the chance that individuals, starting at the time of fertilization of the egg, will complete normal reproductive cycles. Thus, in a population in genetic equilibrium—that is, one in which the appearance of unfavourable genes by mutation is exactly balanced by elimination—the total of reductions in fertility could be estimated to a first approximation if all unfavourable mutations could be detected and counted.

32. Many calculations have been made concerning the

possibility of general reduced fertility as a consequence of increased mutation rate. In the light of these, the Committee considers that the human race appears to have sufficient reserve capacity for breeding to make the possibility of its slow extinction by reduced fertility of genetic origin due to doubling of the normal mutation rate by any mutagenic agent seem very remote.<sup>1110</sup>

#### *Pool of unfavourable recessive genes<sup>1111-1112</sup>*

33. Although not directly related to the social burden caused by mutation, the attempt to measure the total of unfavourable recessive genes per individual in the population is of great interest.<sup>1113</sup> This can be done, because matings occur between related individuals, such as cousins. There is a predictable chance that the offspring of such a mating will receive two identical copies of the same gene from a common ancestor, one copy through the mother and one through the father. If the gene has a visible effect and is recessive, it will show up in these homozygous progeny more often than in the population at large. In this way, it has been estimated that each individual in the general population carries on the average about one or at most three unfavourable recessive genes of a kind giving rise, when homozygous, to some specific detectable clinical entity.<sup>1114</sup>

34. It is also possible to estimate the over-all effect of unfavourable recessive genes by examining the vital statistics of cousin marriages. Although the available data are somewhat limited and inconsistent, it appears that the average individual may well contain a number of unfavourable recessive genes having a total effect equivalent to that of 3 to 5 genes, each of which would, if homozygous, cause failure to survive to maturity.<sup>1115</sup> Comparison of these two estimates, the specific and the general, can in principle give some indication of the proportion of the total unfavourable effect of recessive genes upon reproduction and survival that is mediated through specific clinical entities detectable at the present time. Because the specific conditions studied have an effect less extreme than total failure to reproduce, this proportion may perhaps lie in the neighbourhood of one-third or one-tenth.<sup>1116</sup>

#### **SUMMARY Conclusions**

35. It is accepted that radiation-induced mutations are, in general, harmful and increase in direct proportion to the genetically significant exposure, even at very low dose levels; and that a dose of between 10 and 100 rads per generation would probably be required to double the natural mutation rate in human populations. About 4 per cent of all births are affected with hereditary disorders, some one-quarter of which appear to be at least largely determined by single gene differences. On this basis, an increase in the mutation rate would eventually result in a directly proportional increase in a part of this 4 per cent, amounting to more than one quarter but less than the whole of it. In addition, there would be some changes in other hereditary characteristics of a less sharply defined nature, but the probable extent of these and their importance cannot be assessed at the present time. The Committee concludes from the foregoing genetic facts that exposures to ionizing radiation should be reduced wherever possible, and that medical and industrial procedures tending to increase radiation levels to which human populations might be exposed should be carefully weighed as to such benefits or hazards as each may have.

#### *Areas of uncertainty*

36. The chief uncertainties associated with an attempt to assess the consequences of a given increase in radiation centre around the following:

(a) The dose required to double the mutation rate, is, for the present, believed to be reliable only within a ten-fold range.

(b) Any assessment of the present extent of hereditary defects in the population simply in terms of affected people is admittedly an incomplete measure of "social consequences", which can in any case vary from country to country with the social environment.

(c) The proportion of the hereditary defects which is maintained by recurrent mutation is not at all certain. In the absence of adequate and appropriate observations on the workings of selection pressures in man, present opinions have had to be based on essentially crude criteria.

(d) The possible extent to which irradiation would affect human biometrical characters, their range and mode of variation, is at present largely a matter of speculation.

(e) The effect of a future environment on the magnitude of the "social burden" is not known. Improvements in social, medical, and biological procedures which can be brought to bear on human populations might lessen the effects of some of the deleterious changes. However, such influences could also operate in the opposite direction. Therefore, we cannot predict how future changes in environment will interact with any hereditary alterations so as to influence the general and the individual states of health in future human populations.

#### *Indications for research*

37. Although much is known, quantitative estimates of the mutational consequences of genetically significant irradiation of human populations remain subject to grave limitations, especially in the areas just outlined. These limitations underlie several of the recommendations for genetic research made by a study group of the World Health Organization in a report submitted to this Committee and now published. The Committee draws the attention of the General Assembly to these recommendations, and, in particular, to the following areas of research:

(a) Studies of children whose parents have received substantial radiation exposure, together with investigations of natural mutation rates in man;

(b) Studies of the reproductive patterns both of diverse human populations and of carriers of detrimental genes;

(c) Studies relevant to the genetics of biometrical characters in man, such as intelligence or life-span, and of balanced selective systems in general;

(d) Any other studies which shed light on induced or natural mutation rates in man or in cells of human tissues;

(e) Studies on the production by ionizing radiation, especially at low doses, of mutations and related events in a variety of materials but particularly in the cells of mammals;

(f) Studies of the effects of irradiation on whole populations;

(g) Studies of the mutation event itself, including the time and manner in which the mutational process can be influenced;

(h) Comparative studies of the mutations which occur naturally and those which are induced by different ionizing radiations.

38. Certain measures would expedite the needed research on human populations: extended support of the existing research institutes for human genetics, to make possible the undertaking of long-term research programmes, development of new research centres as com-

petent specialists become available, and collaboration with human geneticists by agencies dealing with vital statistics, public health, and demography with a view to making their data more accessible and suitable for genetic analyses. The lines of research pursued must, however, cover a very wide range; experimentation on a variety of plants and animals is essential and is complementary to work on man.

## Chapter VII SUMMARY AND CONCLUSIONS

1. In estimating the possible hazards of ionizing radiation, it is clearly necessary to know both the levels of such radiation received by man and his environment from various sources, and the present and future effects likely to be produced thereby. It is of particular importance to assess the effects of radioactive fall-out from nuclear weapons, since this source of general environmental contamination is of recent origin, has been of uncertain significance, and has led to concern in the minds of many people. All sources of radiation must, however, be reviewed for a complete evaluation of the situation.

2. The Committee, aware of the complexity of this task, knows that our present information about radiation levels and effects is inadequate for an accurate evaluation of all hazards, and that many of the estimates will necessarily be approximate or tentative.

3. The physical characteristics of ionizing radiation, and the amounts of human exposures to it, are at present more accurately known than its biological consequences, especially where small doses and dose rates are concerned. In the present chapter, therefore, we review first the amounts of radiation received by man, both in regard to the exposure of individuals and of whole populations, and in respect to present and possible future levels. We then attempt to estimate the biological effects of varying amounts of radiation of different types, and to evaluate the hazard resulting from certain sources of particular significance.

4. The relevant physical data refer to the world's population as a whole, as well as to individuals and groups of people receiving relatively higher exposures because of their occupation or place of living. These exposures may involve the whole body uniformly, or may be greater for certain organs or tissues, as when radioactive material is selectively concentrated in them.

5. Tissues of the embryo, of the bone and bone marrow, and of the gonads are of particular importance. Irradiation of the embryo (and of the foetus) may lead to abnormalities of development or may prove fatal. Irradiation of bone marrow and of bone may give rise to leukemia and to bone tumours, and these tissues are subjected to higher doses than other tissues of the body by radioactive materials such as strontium-90 and radium which become concentrated in bone. Irradiation of the gonads is able to bring about changes in the hereditary material; and these may be transmitted to subsequent generations if the irradiation is received before or during the years of reproductive activity.

6. As with any scientific assessment, the conclusions of this report must be subject to revision in the light of advancing knowledge; and the Committee hopes that the report itself, after submission to the General Assembly, will assist this advance by stimulating critical discussion amongst scientists. In view of the complex nature of the subject, individual sentences or assessments may easily be misunderstood unless related to the context of the report as a whole.

### I. LEVELS OF RADIATION

7. Table 1 summarizes our estimates of the average amounts of radiation likely to be received by populations during specified periods, and gives the basis for a comparison between the amounts received from natural and artificial sources. The method of calculation is described in chapter III, the averaging periods of 30 and 70 years being used as relevant respectively to transmissible genetic changes and to somatic injury during the lifetime of an individual. The estimates for medical examinations and occupational exposures are based upon the present situation in certain countries with developed facilities, rather than on a forecasted world average. The values quoted for various hypothetical future circumstances are not intended as predictions, but are calculations based on assumptions discussed in chapter III, and the values and ranges are subject to all the uncertainties outlined there.

#### Radiation from natural sources

8. The radiation received by man from natural sources varies somewhat from place to place according to the local radioactivity of the earth's surface; and that of only occasional populated areas exceeds the average by a factor of 10. Studies on populations living in these areas are of extreme interest for the development of our knowledge on the effects of small doses of radiation. The contribution from cosmic rays differs at different altitudes and geomagnetic latitudes. That from the normal radioactive potassium and carbon content of the body is about the same in different people, but the radiation due to radium, thorium and their decay products varies considerably. The radioactivity of the masonry used for some types of dwelling may appreciably increase the radiation exposure of the occupants. The variations in levels of irradiation from natural sources are discussed in chapter III; the magnitude of these variations, as well as of the average level, is informative in making comparisons with exposures due to artificial sources. Harmful effects attributable to radiation from natural sources are not known with any certainty, but it seems likely that some genetic, and possibly some somatic, injury is caused in this way.

#### Exposure due to medical procedures

9. It is useful to estimate this exposure, appropriately averaged over whole populations, since the genetic, and perhaps some somatic, effects of these procedures will depend upon this average value. In the countries with extensive medical facilities where its magnitude has been estimated, the radiation given for medical purposes makes the largest artificial contribution to the irradiation of the population, but no data are available for countries with fewer such facilities. The reported values of genetically significant doses are of the same order as the doses from natural sources. Among medical procedures, the contribution from diagnostic X-ray examinations greatly exceeds that from radiotherapy and radioisotope applications, the latter making only a small contribution; and

TABLE 1. ESTIMATED DOSE FROM DIFFERENT RADIOACTIVE SOURCES  
(Computed from world-wide averages)

| Source                                                                                               | Genetically significant dose<br>Maximum for any 30 year period (rem) <sup>(1)(2)</sup> |                             | Per capita mean marrow dose<br>Maximum for any 70-year period (rem) <sup>(3)</sup> |                              |
|------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|-----------------------------|------------------------------------------------------------------------------------|------------------------------|
| Natural sources.....                                                                                 | 3                                                                                      |                             | 7                                                                                  |                              |
| Man-made sources (except environmental contamination and occupational exposure) <sup>(4)</sup> ..... | 0.5-5                                                                                  |                             | Ranges beyond 7                                                                    |                              |
| Occupational exposure <sup>(5)</sup> .....                                                           | Less than 0.06                                                                         |                             | 0.1-0.2                                                                            |                              |
| Environmental contamination (hypothetical cases) <sup>(6)</sup> .....                                |                                                                                        |                             | Estimates for countries deriving most of dietary calcium from milk                 |                              |
| Weapon tests cease at end of 1958.....                                                               | 0.010                                                                                  |                             | 0.16                                                                               |                              |
|                                                                                                      | Assumption A <sup>(7)</sup>                                                            | Assumption B <sup>(8)</sup> | Assumption A <sup>(9)</sup>                                                        | Assumption B <sup>(10)</sup> |
| Weapon tests continue until equilibrium is reached in about a hundred years <sup>(11)</sup> .....    | 0.060                                                                                  | 0.12                        | 1.3                                                                                | 2.8                          |
|                                                                                                      | Assumption A <sup>(7)</sup>                                                            | Assumption B <sup>(8)</sup> | Assumption A <sup>(9)</sup>                                                        | Assumption B <sup>(10)</sup> |
| Estimated percentages of the maximum doses for continued weapon tests                                |                                                                                        |                             |                                                                                    |                              |
| Weapon tests cease                                                                                   | 17                                                                                     | 9                           | 13                                                                                 | 6                            |
| 1958.....                                                                                            | 42                                                                                     | 33                          | 24                                                                                 | 16                           |
| 1968.....                                                                                            | 64                                                                                     | 56                          | 34                                                                                 | 26                           |
| 1978.....                                                                                            | 79                                                                                     | 67                          | 40                                                                                 | 33                           |
| 1988.....                                                                                            | 100                                                                                    | 100                         | 100                                                                                | 100                          |

<sup>(1)</sup> For countries having an extensive use of the radiation sources listed and reporting data to the Committee.

<sup>(2)</sup> Doses for certain technologically highly developed countries only.

<sup>(3)</sup> Computed from population weighted world-wide average of atmospheric fall-out rate and deposit.

<sup>(4)</sup> Regional values may differ by a factor of about 1/4 to 2 from the estimated population weighted world-wide average values because of the latitudinal variation of fall-out rate and deposit. In some areas of the world the tropospheric fall-out may tend to raise the upper limit of this range, especially in the vicinity of that area.

<sup>(5)</sup> The extent to which these estimates apply to populations of different dietary habits and to those living in areas of differing

soil conditions is discussed in paragraph 69 of chapter III.

<sup>(6)</sup> Assumption A is that the injection rate is such as to maintain a constant fall-out rate of strontium-90 and cesium-137, whereas assumption B is that weapon tests equivalent in release and stratospheric injection of fission products to the whole sequence of weapon tests from the beginning of 1954 to the end of 1958 will be repeated at constant rate. This second assumption will give an equilibrium value for the fall-out rate and deposit approximately a factor of 2 higher than that calculated by using the first assumption.

<sup>(7)</sup> The values for the 30-year doses have been corrected for tropospheric fall-out in accordance with paragraph 57 of chapter III, using a value of 0.5 mrem/year for the period of testing.

80 to 90 per cent of the total diagnostic dose to the gonads is due to relatively few types of examination of the abdomen and pelvis.

10. Most of these values are preliminary estimates, and further investigations are needed, for which procedures have been suggested by the International Commissions on Radiological Protection and on Radiological Units and Measurements in a report prepared at the request of this Committee and submitted to it in document A/AC.82/G/R.117.

11. The significant dose to bone and bone marrow from medical procedures has been less closely studied than the genetically significant dose, although it may be of importance if bone tumours or leukemia are induced by radiation at low dose levels. Although individual marrow exposures vary very widely, the average is unlikely to differ greatly from that received by the marrow from all natural sources.

12. The contribution made by medical procedures to the radiation exposure of populations has only lately been estimated and has increased very rapidly in some countries in recent years, so that it is difficult to evaluate such genetic and somatic effects as are associated with an increasing employment of radiological procedures in medicine. No information is yet available for prediction

of the future trend of medical exposures. It is expected that improvements in equipment and techniques may considerably reduce individual exposures, but the ever-expanding use of X-rays may well increase the world population dose. Precautions of the type described by the International Commissions on Radiological Protection and on Radiological Units and Measurements should make possible such reduction of exposure to radiation as is without detriment to the medical value of these procedures.

#### Occupational exposure

13. At present, the exposure to ionizing radiation received occupationally forms only a small contribution to the total irradiation of the population as a whole, amounting to about 2 per cent of that from natural sources in countries in which occupational exposure is probably largest. With an increasing use of nuclear reactors, of radioactive materials and probably of medical and industrial radiological procedures, this is clearly a figure which should be kept under close review. Although this source does not appear likely to make a substantial contribution to the total radiation exposure of populations in the immediate future, the occupational exposure of some individuals may represent a large fraction of their total radiation exposure.



14. Since 1928, the International Commission on Radiological Protection has recommended "maximum permissible doses" for those who are occupationally exposed to radiation, and has proposed appropriate methods of measurement. Their present recommendations, which have recently been reviewed in the light of progress in radiobiological knowledge and which propose reductions in dose levels, may not be final but are at present widely accepted as a sound basis for the protection of those exposed occupationally to ionizing radiation.

#### Radioactive wastes

15. The discharge of radioactive waste in countries with nuclear reactors has not led to appreciable radiation exposure of populations, and only small proportions of the wastes produced need to be discharged. The likely future extension in the use of such reactors, however, and the possibility of accidental releases of fission products, clearly require that this subject be kept under review. It is important that work should be actively continued on methods of minimizing environmental contamination from these causes.

#### Radiation from fall-out

16. Fall-out from nuclear weapon tests causes radiation exposure in several ways (chapter III). Exposure of the world population results from the slow fall-out of fission products which have been distributed in the stratosphere. Exposures also result from any fall-out from the radioactive "cloud" which passes through the troposphere without having reached the higher stratosphere, and from the fall-out which may occur in areas adjacent to weapon tests or within some thousand kilometres of them.

17. We also consider the ways in which fall-out material causes irradiation to different parts of the body, to people on different diets or under different agricultural conditions, and to people of different ages; and the change in the amounts of radiation that would result from altered or unaltered rates of injection of radioactive materials into the stratosphere.

#### Fall-out adjacent to tests

18. The early fall-out of radioactive materials near to the sites of nuclear explosions, which is influenced by various meteorological and testing conditions, may cause high radiation exposure to individuals within these areas. The amount of such radiation exposures varies very greatly with the weapon tested, with the height of firing, with the distance from the point of explosion, with the direction of winds at various altitudes and with the chance occurrence of rainfall through radioactive material in the early hours after the test. Therefore, at present, these doses cannot in general be calculated. Under very special conditions, high radiation exposure and deleterious effects have been reported, as in the cases of the Marshall Islands and the crew of a Japanese fishing vessel. Not enough information is available as to the general circumstances in which such local deposition may occur, and the extent and duration of the exposures liable to be involved.

#### Fall-out from the troposphere

19. Radioactive materials injected into the atmosphere below the tropopause (at about 14 km) are brought down to the earth's surface by rainfall and sedimentation. This process takes a few months during which they are car-

ried several times around the world. This tropospheric fall-out consists of a mixture of radioactive materials, most of which are short-lived isotopes. At the present time, the tropospheric fall-out is deposited intermittently during the year and a certain deposit of short-lived activities is built up and maintained. When appropriate factors for shielding and weathering effects are included, the gonad and average marrow dose from this deposit, as an external source, is calculated to be about 0.5 mrem per year.

20. Transient increases of the doses from tropospheric fall-out have been observed in limited areas shortly after weapon tests. These transient increases may give rise for a few days to dose rates of the order of those from natural sources.

21. The radioisotopes of tropospheric fall-out may be taken up into the body by inhalation and ingestion. Since the radioisotopes of principal concern are short-lived, storage of the contaminated food products reduces the dose which they contribute. The gonad dose over the whole population from inhaled and ingested tropospheric material is negligible as compared with the contribution from this material as an external source. The average bone marrow dose from internal sources is about 0.2 mrem per year.

22. Increases in radioactivity of the thyroid gland have been found during periods of several weeks or a few months following weapon tests. In human thyroids a dose from iodine-131 of about 5 mrem per year has been estimated for 1955-1956 in the United States excluding areas immediately adjacent to weapon test sites. Doses of this order are unlikely to cause detectable damage or functional change in the gland.

23. Irradiation of bone may result from incorporation of intermediate and short-lived fission products. Although these materials do not cause prolonged irradiation, they may become selectively concentrated into those areas of bone in which active growth is taking place at the time, and so cause more intense radiation locally than if the same amounts of these materials were distributed throughout the whole skeleton.

24. The Committee has insufficient information on local variations and temporary increases of tropospheric fall-out in populated areas at different distances from weapon test sites, and emphasizes the lack of further data which would permit evaluation of the biological significance of this source of environmental contamination.

#### World-wide fall-out from the stratosphere

25. Radioactive materials injected into the stratosphere, especially by high-yield nuclear explosions, constitute a reservoir from which they fall onto the whole of the earth's surface for many years. The rate of fall-out varies with latitude and is greater in the northern hemisphere, where most of the tests are carried out. Within any given small area, fall-out rate may also vary with local meteorological conditions. The figures given in table I are computed from world-wide average deposits from stratospheric fall-out. The radiation due to stratospheric fall-out from weapons exploded so far will contribute a 30-year gonad dose of 10 mrem, and a 70-year *per capita* mean marrow dose of 160 mrem and 960 mrem for two populations deriving most of their dietary calcium from milk and rice respectively.

26. Owing to the relatively gradual fall-out from the stratosphere, most of the subsequent radiation is due to two radioactive isotopes of slow decay, other fission

products already having largely undergone decay. These two radioactive isotopes are caesium-137 and strontium-90. The physical properties and chemical behaviour of the two differ.

27. Caesium-137 is responsible for most of the gonad radiation from fall-out noted in table I. When it is taken into the body, it becomes distributed more or less evenly throughout the tissues, causing uniform irradiation of the whole body; and when present in the surroundings, its penetrating gamma radiations cause a similarly uniform irradiation of tissues.

28. Strontium-90, on the other hand, is not a gamma-emitter and does not contribute significantly to the irradiation of any part of the body from without. However, on being taken into the body, it becomes incorporated in bone because of its chemical similarity to the normal bone-forming element calcium. This similarity with calcium and selective concentration in bone raises problems which do not occur with caesium-137.

29. The average concentration of strontium-90 in the bones of children, in whom new bone is continuously being formed, is higher than in adults whose bones were largely formed before the environment, and consequently the food supply, became contaminated with strontium-90. The highest concentrations of strontium-90 in bone have in fact been observed in children from a few months to five years old. The bone marrow exposures from fall-out given in table I are due to the strontium-90 content of bone and refer to the concentrations estimated for children of these ages. The corresponding exposures of bone cells from fall-out are; on the average, about three times the values for bone marrow. Marrow cells almost enclosed by bone would receive doses similar to those in compact bone. The maximum marrow dose could differ by a factor of about 5 from the average level.

30. The radiostrontium concentration in bone is also affected by dietary habit and by the ratio of the amounts of strontium-90 to calcium in the diet. At present this ratio differs in various dietary constituents; it is higher in brown rice than in white, somewhat higher in many vegetables than in milk products, higher in rain-water than in river water, and lower in sea fish than in fresh-water fish.

31. Agricultural conditions may also affect the content of strontium-90 in the diet, since the available calcium of the soil will, within certain limits, influence the ratio of strontium-90 to calcium in crops derived from the soil. The distribution of soils which are highly deficient in calcium and their utilization require further study. More work is also needed to understand the distribution of strontium-90 in the soil, its chemical availability to plants and uptake through their roots, its behaviour under ploughing and the leaching of it from soil by the action of water, since the figures in table I for future strontium-90 levels in bone are calculated on the assumption that this material will not be leached from soil, and this assumption may lead to unduly high values.

32. Bone marrow exposures from fall-out are given in table I for two conditions: one based on observations in the United States of America and the United Kingdom, where milk is the main source both of dietary calcium and of strontium-90, and where soil calcium contents are commonly high; and the other based upon data from Japan where milk products are much less used and where rice and other vegetable products form the main source

of dietary calcium and strontium-90, and where low calcium soils are frequent. These two estimates demonstrate the present range of known dietary contaminations. They will be used in an attempt to estimate the hazard of radiation from fall-out in paragraph 57 below, when the nature and frequency of the biological effects of radiation have been considered.

33. It is evident that the radiation exposures from fall-out which are most likely to be of significance are:

- (a) Those from short-lived fission products and radioactive material due to local or tropospheric fall-out;
- (b) Those of the gonads and other organs from caesium-137 due to stratospheric fall-out;
- (c) Those of bone and adjacent tissue from strontium-90 which also comes largely from the stratosphere. The relative importance of these contributions varies from region to region.

#### II. BIOLOGICAL EFFECTS OF RADIATION

34. The biological effects of ionizing radiation are exhibited in different ways according to whether isolated cells, tissues, organs or organisms are examined. In passing from unicellular to higher organisms, the primary physicochemical consequences of radiation become increasingly influenced by secondary effects due to the reactions of the organism to the primary events. Detailed knowledge of these reactions is needed for a full understanding of the results and mode of action of radiation. The following paragraphs deal first with the cellular effects of radiation; then with the somatic effects on the irradiated individual and with the genetic effects on his progeny.

35. The effects of ionizing radiations on living matter are extremely complicated, and their exact mechanisms are still largely unknown. The initial disturbance is associated with ionization (and excitation) of molecules which lead to alterations in their properties. Many functions of the cell are thus affected by radiation, and, although some specific effects may be caused by one or a few events in the cell, many are probably the combined result of numerous such events.

36. The minimum doses causing certain detectable biological effects differ very much in different organisms, but for most mammals they are of about the same magnitude, so that the results of experiments on such animals can, as a first approximation, be applied to man. The sensitivity of different tissues to radiation varies considerably, however. Our knowledge of the biological effects of low radiation levels is meagre because of experimental difficulties and the lengthy observations necessary to obtain results in this field. At present, opinions as to the possible effects of low radiation levels must be based only on extrapolations from experience with high doses and dose rates.

#### Effects of radiations on man

37. Man may prove to be unusually vulnerable to ionizing radiations, including continuous exposure at low levels, on account of his known sensitivity to radiation, his long life, and the long interval between conception and the end of the period of reproduction.

38. Embryonic cells are especially sensitive to radiation, and some evidence suggests that exposure of the foetus to small doses of radiation may result in leukemia during childhood. Irradiation of pregnant mammals has shown that doses exceeding 25 rem to the foetus during

certain stages of its development can cause abnormalities in some organs. Some embryonic cells (neuroblasts) of certain species cultivated *in vitro* respond to doses as small as 1 rad. If these results should be applicable to man and since they relate to the development of the brain, the opinion seems justified that even a very small dose to the human fetus may involve some risk of injurious effects if received during a critical period of pregnancy. Radiostrontium must be expected to enter foetal bone when calcification starts in the second trimester of pregnancy, and so cause irradiation of the adjacent developing nervous system and hypophysis with exposures ranging up to that occurring in the bone. The uptake of radiostrontium in foetal bone tissue is, however, at present very small, contributing less radiation than 1 per cent of that due to natural sources; but if the present rate of test explosions is continued, it will rise ultimately to some 10 per cent of that due to natural sources.

39. Children are regarded as being more sensitive to radiation than adults, although there is little direct evidence on this subject, except for an indication that cancer of the thyroid may result from doses of a few hundred rad which do not induce this change in adults.

40. In human adults it is difficult to detect the effect of a single exposure to less than 25 to 50 rem, or of continuing exposure to levels below 100 times the natural levels. The first sign of radiation damage to the blood-forming tissues seems to be a drop in the number of lymphocytes and platelets and the appearance of abnormalities such as bilobed lymphocytes.

41. Rapid but transient disturbances have been observed in mammals after exposure to a single dose of 25 to 200 mrem. Appropriate biochemical and physiological techniques have, however, only recently been applied to the study of irradiated organisms, and have not yet given a clear picture of what happens to organisms irradiated with small doses or dose rates. Too few mammalian species have hitherto been studied in this respect, and there is a clear need to widen this basis, from which inferences can be drawn concerning man.

42. Processes of repair play an important role in the final outcome of radiation damage. They are one cause of the existence of a threshold dose (or dose rate) characterized by the fact that this dose or greater ones produce a particular biological effect which does not appear when the dose is less than the threshold. In the latter case, physicochemical events have occurred, but recovery processes have prevented the final appearance of the biological damage. Threshold doses are found for some somatic effects, such as erythema of skin. Other forms of radiation damage to cells, tissues or organisms, however, appear to be cumulative; for instance, mutational damage, once established, is not repaired.

43. Damaged cells or tissues may be eliminated and replaced by regenerated normal cells, this process being most active in embryos and young animals and in certain tissues of the adult. The affected cells may also re-establish apparently normal biochemical functions. During the process of regeneration of tissues damaged by radiation, malignant tumours may be induced.

44. The power of repair differs considerably in different organisms and types of cells, and varies to a high degree with the physiological conditions. No chemical treatment has yet been discovered which will induce or accelerate recovery from radiation damage in man. The

grafting of blood-forming tissue has so far been successful only in small mammals irradiated with a lethal dose to the whole body, and no attempt to apply this treatment to irradiated man has yet been reported.

45. Prevention of the effects of radiation is rendered more difficult, and complete protection against it impossible, because changes which already occur during the irradiation lead to later damage. The discovery of chemical protectors, although important theoretically, has not yet yielded methods which appreciably reduce radiation damage in man. At present, effective protection from external radiation sources can only be achieved by adequate shielding or by keeping at a safe distance from the source. Much work is in progress on the effect of certain (chelating) agents in discharging from the body radioisotopes incorporated there, and so diminishing exposure to internal irradiation.

46. Morphologically recognizable damage may be induced by total or partial, continuous or intermittent irradiations much in excess of the currently accepted "maximum permissible levels" of occupational exposure. Such damage includes leucopenia, anemia and leukinemia. Other pathological conditions such as cataract, carcinoma of the thyroid, and bone sarcoma are known to have resulted from partial body irradiations, but with rather high doses involving hundreds or even thousands of rem given to these organs.

47. The shortening of the life-span in small rodents exposed to large doses has suggested the possibility that certain degenerative processes may be aggravated by continued exposure to low radiation levels. Such a shortening has also been inferred from an analysis of the published death rates of United States radiologists compared with those of certain other groups of medical men. However, studies in the United Kingdom have failed to demonstrate such an effect.

48. Present uncertainty about the effects of low dose levels makes it imperative that as much relevant information as possible be collected about groups of persons chronically exposed at these levels and for whom adequate control groups exist, for instance, certain populations in areas of high natural radiation and workers in uranium mines.

49. Exposure of gonads to even the smallest doses of ionizing radiations can give rise to mutant genes which accumulate, are transmissible to the progeny and are considered to be, in general, harmful to the human race. As the persons who will be affected will belong to future generations, it is important to minimize undue exposures of populations to such radiation and so to safeguard the well-being of those who are still unborn.

50. The present assumption of the strictly cumulative effect of radiation in inducing mutations in man is based upon some theoretical considerations and a limited amount of experimental data obtained by exposure of experimental organisms to relatively high dose levels. This assumption underlies all present assessments of the mutational consequences of irradiation. Therefore, extension of the experimental data to the lowest practicable dose levels is needed.

51. The knowledge that man's actions can impair his genetic inheritance, and the cumulative effect of ionizing radiation in causing such impairment, clearly emphasize the responsibilities of the present generation, particularly in view of the social consequences laid on human populations by unfavourable genes.

52. Besides increasing the incidence of easily discernible disorders, many of them serious but each comparatively rare, increased mutation may affect certain universal and important "biometrical" characters such as intelligence or life-span. In this way, it is possible that a continued small genetically significant exposures of a population may affect, not only a correspondingly small number of individuals seriously, but also most of its members to a correspondingly small extent. While less easy to detect, this second kind of effect on a population could also be serious. Unfortunately, the great majority of the genes affecting the "biometrical" characters are not individually detectable and so can only be studied collectively and with difficulty. In consequence, far less is known about them than about genes responsible for individually detectable changes and very little indeed about their response to irradiation, even in the best-studied experimental organisms. Hence it is impossible, at the present time, to estimate with any assurance the effect upon biometrical characters of any given level of irradiation of human populations. Much further research throughout this field is therefore needed.

53. The Committee emphasizes the urgent necessity for well-planned investigations which may lead to a better understanding of the mechanism of mutation and the eventual possibility of controlling this process. More information is needed on the effect of radiation in inducing mutations in man. Indeed, even the dose required to double the normal mutation rate in man is not known with any accuracy. There is also need for a much closer co-operation between geneticists and demographers in elucidating the nature of the complex process of human selection. Many important subjects of relevant genetic research have been reviewed by a study group of the World Health Organization in their report "Effects of Radiation upon Human Heredity", document A/AC.82/G/R.58.

### III. GENERAL CONCLUSIONS

54. The exposure of mankind to ionizing radiation at present arises mainly from natural sources, from medical and industrial procedures, and from environmental contamination due to nuclear explosions. The industrial, research and medical applications expose only part of the population while natural sources and environmental sources expose the whole population. The artificial sources to which man is exposed during his work in industry and in scientific research are of value in science and technology. Their use is controllable, and exposures can be reduced by perfecting protection and safety techniques. All applications of X-rays and radioactive isotopes used in medicine for diagnostic purposes and for radiation therapy are for the benefit of mankind and can be controlled. Radioactive contamination of the environment resulting from explosions of nuclear weapons constitutes a growing increment to world-wide radiation levels. This involves new and largely unknown hazards to present and future populations; these hazards, by their very nature, are beyond the control of the exposed persons. The physical and biological data contained in the report lead to the conclusion that it is undesirable to allow any general rise in the level of world-wide contamination because of its harmful effects and that any activity which produces such a rise should be avoided. Nuclear tests are the main source at present which produce such a rise. This proposal was rejected by the following roll-call vote: In favour: Brazil, France, India, Japan, United States of America. Against: Argentina, Australia, Mexico, Sweden, United Kingdom of Great Britain and Northern Ireland, United States of America. Abstaining: Belgium (Chairman), India.

involve national and international decisions which lie outside the scope of its work.\*†

55. Certain general conclusions emerge clearly from the foregoing part of this report:

(a) Even the smallest amounts of radiation are liable to cause deleterious genetic, and perhaps also somatic, effects.

\*The USSR submitted a draft proposal for paragraph 54 which, as amended by Czechoslovakia with the agreement of the USSR, read as follows:

"The scientific information received by the Committee indicates that the genetic effects of radiation must be considered reactions for which there is no threshold. This means that any increase in the exposure of the human organism to radiation will lead to an increase in the incidence of hereditary diseases. According to one body of scientific opinion, malignant neoplasms and also leukemias are diseases the incidence of which may increase as the level of radiation rises. These data, together with the fact that there is very little likelihood that the human organism can adapt itself to conditions of increased environmental radiation, indicate that any increase in the radiation dose above the natural radiation level must be considered undesirable for mankind. Efforts should accordingly be made to improve the physical basis and the technique of the medical use of radiation by formulating more precise indications for the use of radiation and by eliminating adverse side effects. It is also essential to develop, on the basis of broad international co-operation among scientists, research on the improvement of protection and safety techniques in atomic industry and in science and technology. The physical and biological data presented in the report make it plain that efforts should be made to eliminate the uncontrolled source of radiation, i.e. to end experimental nuclear and thermonuclear explosions, and enable the Committee to draw the conclusion that there should be an immediate cessation of test explosions of nuclear weapons."

This proposal was rejected by the following roll-call vote: In favour: Czechoslovakia, Union of Soviet Socialist Republics, United Arab Republic.

Against: Argentina, Australia, Brazil, Canada, France, Japan, Mexico, Sweden, United Kingdom of Great Britain and Northern Ireland, United States of America.

Abstaining: Belgium (Chairman), India.

The above text expresses the dissenting view of Czechoslovakia, the United Arab Republic and the USSR to the wording of paragraph 54, which was approved by a majority of the Committee.

†India also submitted a draft proposal for paragraph 54 which, with amendments accepted by India, read as follows:

"The exposure of mankind to ionizing radiation at present arises mainly from natural sources, from medical and industrial procedures, and from environmental contamination due to nuclear explosions. The industrial, research and medical applications expose only part of the population while natural sources and environmental sources expose the whole population. The artificial sources to which man is exposed during his work in industry and in scientific research are of value in science and technology. Their use is controllable, and exposures can be reduced by perfecting protection and safety techniques. All applications of X-rays and radioactive isotopes used in medicine for diagnostic purposes and for radiation therapy are for the benefit of mankind and can be controlled. Radioactive contamination of the environment resulting from explosions of nuclear weapons constitutes a growing increment to world-wide radiation levels. This involves new and largely unknown hazards to present and future populations; these hazards, by their very nature, are beyond the control of the exposed persons. The physical and biological data contained in the report lead to the conclusion that it is undesirable to allow any general rise in the level of world-wide contamination because of its harmful effects and that any activity which produces such a rise should be avoided. Nuclear tests are the main source at present which produce such a rise."

This proposal was rejected by the following roll-call vote: In favour: Brazil, France, India, Japan, United States of America.

Against: Argentina, Australia, Mexico, Sweden, United Kingdom of Great Britain and Northern Ireland.

Abstaining: Belgium (Chairman), Canada, Czechoslovakia, Union of Soviet Socialist Republics, United Arab Republic.

(b) Both natural radiation and radiation from fall-out involve the whole world population to a greater or lesser extent, whereas only a fraction of the population receive medical or occupational exposure. However, the irradiation of any groups of people, before and during the reproductive age, will contribute genetic effects to whole populations in so far as the gonads are exposed.

(c) Because of the delay with which the somatic effects of radiation may appear, and with which its genetic effects may be manifested, the full extent of the damage is not immediately apparent. It is, therefore, important to consider the speed with which levels of exposure could be altered by human action.

It is clear that medical and occupational exposure, and the testing of nuclear weapons, can be influenced by human action, and that natural radiation and the fall-out of radioactive material already injected into the stratosphere, cannot.

56. Present knowledge concerning long-term effects and their correlation with the amounts of radiation received does not permit us to evaluate with any precision the possible consequence to man of exposure to low radiation levels. Many effects of irradiation are delayed; often they cannot be distinguished from effects of other agents; many will only develop once a threshold dose has been exceeded; some may be cumulative and others not; and individuals in large populations, or particular groups such as children and foetuses may have special sensitivity. These facts render it very difficult to accumulate reliable information about the correlation between small doses and their effects either in individuals or in large populations. Even a slow rise in the environmental radioactivity in the world, whether from weapon tests or any other sources, might eventually cause appreciable damage to large populations before it could be definitely identified as due to irradiation. Appearance and elimination of adverse genetic effects would be very slow; and, as the radioactive contamination accumulated, it might so act as to increase the likelihood of somatic injury in individuals due to the additional exposure. Such a situation requires that mankind proceed with great caution in view of a possible underestimation. At the same time, the

possibility cannot be excluded that our present estimates exaggerate the hazards of chronic exposure to low levels of radiation. Only further intensive research can establish the true position.\*\*

57. Any present attempt to evaluate the effects of sources of radiation to which the world population is exposed can produce only tentative estimates with wide margins of uncertainty. Estimates are given in chapter III for the radiation exposure of populations from such sources, and in chapters V and VI for the likely somatic and genetic effects of given exposures. On the basis of these, the Committee has tried to evaluate the possible effect of natural and of fall-out radiation in causing leukemia, tumours of bone and major genetic defects (table II) since these are conditions which may possibly be induced by irradiation at low dose levels. The methods of calculation, and the main sources of uncertainty in these estimates, are described in chapters III, V and VI, where factors of correction are also given for the different estimates corresponding to differences in the assumptions on which the calculations are based. It will be evident that the estimates indicate only the order of magnitude of the frequency with which effects may be produced, and that our ignorance as to whether thresholds exist for the induction of leukemia or bone tumours by radiation cause the greatest uncertainty in the estimates.

#### Indications for research

58. This report presents evidence both of the increasing levels of radiation exposure, and of our uncertainties as to the nature and extent of the effects of radiation on man, particularly when received at low dose rates over long periods. It is most important, therefore, that scientific research and the collection of information on the effects of radiation should be actively continued and developed so that the uncertainties in all branches of radiobiology are reduced or removed.

\*\*The maximum permissible levels of exposure and maximum permissible body burdens of radioactive isotopes recommended in 1954-1955 by the International Commission on Radiological Protection as applying in the case of occupational exposure must not be misinterpreted to apply in the case of exposure of whole populations.

TABLE II. ESTIMATES OF CERTAIN POSSIBLE ANNUAL CONSEQUENCES OF RADIATION RECEIVED BY WORLD POPULATION FROM CERTAIN SOURCES

| Consequence                  | World population assumed (in millions) | Natural occurrence assumed per year | Natural radiation   | Source of radiation        |                                                      |
|------------------------------|----------------------------------------|-------------------------------------|---------------------|----------------------------|------------------------------------------------------|
|                              |                                        |                                     |                     | Fall-out from weapon tests |                                                      |
|                              |                                        |                                     |                     | Tests stopping in 1958     | In equilibrium after prolonged continuation of tests |
| <b>Leukemia</b>              |                                        |                                     |                     |                            |                                                      |
| If threshold 0 rem.....      | 3,000                                  | 150,000                             | 15,000              | 400 to 2000*               | —                                                    |
|                              | 5,000                                  | 250,000                             | 25,000              | —                          | 5,000 to 60,000                                      |
| If threshold 400 rem.....    | 3,000                                  | 150,000                             | 0*                  | 0*                         | —                                                    |
|                              | 5,000                                  | 250,000                             | 0*                  | —                          | 0*                                                   |
| <b>Major Genetic Defects</b> | 5,000                                  | 700,000 to 3,000,000                | 25,000 to 1,000,000 | —                          | 500 to 40,000                                        |

\* Maximum rate during peak period. An estimated total of less than 25,000 to 150,000 would ultimately occur.

\* Unless individual bone marrow dose exceeds mean value by a factor of 60.

\* Unless individual bone marrow dose exceeds mean value by a factor of 80 to 500.

\* Unless individual bone marrow dose exceeds mean value by a factor of 5 to 60.

\* Conditions which are at least a serious handicap to those affected, as listed in table XI of annex II.

\* A total of 2,500 to 100,000 would occur over subsequent years.

NOTES.—The methods of estimating incidences of leukemia and major genetic defects are described in annex D, paras. 127 to 130.

The quantitative evaluation of an increase in incidence of primary bone tumour attributable to radiation presents great

difficulties. If it were assumed that 5 to 10 cases per million normally occurred per year, and that 10 per cent of these were induced by natural radiation the following figures could be calculated from the 70-year osteocyte dose if a non-threshold hypothesis were assumed:

For tests stopping in 1958 and world population 3,000 million, 70 to 900 per year (as the maximum rate).

In equilibrium after prolonged continuation of tests and world population 5,000 million, 1,000 to 25,000 per year (as the continuing rate).

If a threshold of 400 rem were assumed, the incidences would be zero unless individual osteocyte doses exceeded the mean value by a factor of 80 to 500 in the case of tests stopping in 1958 and by a factor of 5 to 60 in equilibrium after prolonged continuation of tests.

59. Our knowledge of radiation and of its hazards is not however static; although still limited, it has been expanding rapidly. In recent years, considerable and sometimes spectacular advances have been made in our understanding of many of these matters. In the light of general scientific experience, the Committee confidently expects that continuing research on an increasing scale will furnish the knowledge urgently needed to master those risks which we know to be associated with the development and scope of the uses of nuclear energy for the welfare of mankind.

#### Indications for research into radiation levels

60. The doses received by both individuals and whole populations from various sources are not yet adequately known. Consequently,

(a) The range of tissue dose rates due to natural radioactivity, particularly in heavily populated areas with adequate demographic records, as well as the variations in content of natural radioactive substances in human beings need further examination;

(b) Fuller information is required as to the exposure of various populations to radiation during industrial procedures and during medical procedures, especially in so far as this involves children or foetuses and exposure of the bone marrow or gonads. It would be valuable if these further investigations could provide (i) a more representative estimate for some countries already studied, (ii) a fuller study of the dosage associated with the varied extent of medical facilities in different countries, (iii) clearer estimates of the radiation given to different tissues, including bone, (iv) the contribution from radiotherapy and (v) a continuing study of future developments and of changes in the medical radiation exposure;

(c) More extensive research is required on the fate of industrial radioactive effluents of various types and on the prevention of radiation exposures of populations from this source;

(d) Many factors which determine the distribution of local, tropospheric and stratospheric fall-out from

experimental nuclear explosions require further investigation. In particular, more evidence is required on the behaviour of fission products in the stratosphere. Collation of information is needed to determine the pattern and extent of global fall-out on land and oceans. Far more extensive information is needed as to the mechanisms whereby fission products, particularly strontium-90 and caesium-137, reach food-chains and enter the human body, as well as the concentration of those materials in human tissues, particularly under the conditions where this is likely to be greatest.

#### Indications for research into biological effects

61. Information concerning the biological effects of irradiation of man is derived from experimental biology, and from clinical observations and statistical surveys.

(a) All advance in radiobiology depends upon progress in general cellular biology, and requires intensive study of the fields concerned.

(b) Fundamental biological knowledge is required for our understanding and control of the way in which radiation influences cells and their hereditary material, and how it brings about carcinogenesis. Further studies of these phenomena are needed, and form the only satisfactory basis for measures which could be adopted to prevent or cure the harmful effects of radiation.

(c) To identify any occasional harmful effects of low doses and dose rates requires systematic and long-term observation and the recording of relevant facts, especially concerning the frequency of certain somatic disorders and the genetic structure of populations. It is a task to which this Committee urgently draws the attention of demographers and medical statisticians, especially in regard to possible correlation of certain diseases with high natural or artificial radiation exposure.

#### Training for research

62. The advance of research in all these fields depends upon appropriate training of scientific workers.

# A COMMENTARY ON THE REPORT OF THE UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION

The Committee on Pathologic Effects of Atomic Radiation of the National Academy of Sciences - National Research Council has continued to function since the issuance of its report\* in June 1956 as part of a study by the National Academy of Sciences - National Research Council Committees on the Biological Effects of Atomic Radiation. Several of its members have worked closely with the United Nations Scientific Committee on the Effects of Atomic Radiation and therefore have been cognizant of the discussions which went on in the United Nations Committee leading to its report and various annexes.\*\* It is gratifying in reading the report of the United Nations Scientific Committee to note that it has drawn upon the reports of the National Academy of Sciences - National Research Council Committees.

Our Committee on Pathologic Effects of Atomic Radiation offers sincere congratulations to the United Nations Scientific Committee on the Effects of Atomic Radiation for its report published on August 10, 1958. This represents the most comprehensive study of effects of ionizing radiation ever undertaken and brings together in compact form a tremendous body of information derived not only from the knowledge available in the 15 nations represented on the Committee but also from that of all of the States Members of the United Nations and its Specialized Agencies.

Of unusual interest is the wide geographic coverage provided by the fallout data. We share the reservations of the Committee of the Medical Research Council of the United Kingdom with regard to possible future levels of fallout. Conclusions based not only on assumptions of unpredictable future events but also on broad scientific assumptions as to the distribution of fallout material in man's environment are necessarily uncertain.

\* Report of the Committee on Pathologic Effects of Atomic Radiation (Publication 452 of the National Academy of Sciences - National Research Council, Washington, 1956).

\*\* Report of the United Nations Scientific Committee on the Effects of Atomic Radiation (General Assembly, Official Records: Thirteenth Session, Supplement No. 17, Doc. A/3838, New York, 1958).

The global character of the report is emphasized by considerations of subjects to which we, in this country, would ordinarily not give attention, such as marked dietary differences in different areas. For example, the estimates of radiostrontium uptake in our own and in western European countries were based on the derivation of the bulk of dietary calcium from milk, whereas great masses of populations in the Orient derive most of their dietary calcium from rice. This approach, taking cognizance of situations peculiar to specific regions and variations in dietary habits, serves to emphasize the unanimity of the general trend of opinion among the scientists drawing up the report for the United Nations Scientific Committee on the Effects of Atomic Radiation, as well as the report of the Medical Research Council of the United Kingdom\* and our own in 1956.

We will comment directly on the annexes to the report only to say that they contain a vast mass of source material and a number of useful calculations.

In those portions of the United Nations report that deal with pathologic effects there are several points on which we are not entirely in agreement and are constrained to make clear our position. These minor points should not cloud our general agreement with and admiration for the report of the United Nations Scientific Committee. We believe, however, that it would be useful to make the following particular comments:

1) The question of induction of leukemia or other types of cancer in man by very small doses of radiation has been treated in the United Nations report to suggest that the hypotheses of linearity and threshold effects as applied to the behavior of somatic cells have equal likelihood of validity. Our committee inclines to the view that many forms of cancer, including leukemia, arise through a more or less complex series of responses. While somatic mutations may be included among these, it seems doubtful that a strict linearity analogous to that seen in the genetic effects of radiation is as likely to hold in the case of these conditions. We note also that there is a considerable body of experimental evidence favoring non-linearity in specific instances. Also, the report seems largely to emphasize the two extreme possibilities, that of a linear relation and of a threshold, and gives little attention to non-linear relations. It is recognized that large-scale definitive experiments and demographic observations are needed since they may be of help in resolving these questions.

2) Knowledge of the incidence of leukemia and other tumors as well as of the mechanism of radiation tumorigenesis is too incomplete to permit accurate estimates of numbers of cases of radiation-induced leukemia, bone cancer, or other types of tumors. We recognize that the tabulation

\* Medical Research Council, The Hazards to Man of Nuclear and Allied Radiations (London, Her Majesty's Stationary Office, 1956).



given by the United Nations Scientific Committee present estimates which range from zero to some thousands of cases and hence imply much uncertainty. We are concerned that greater validity may be ascribed to these figures than the basic data warrant.

3) There is perhaps too great an impression created that leukemia is an inevitable result of radiation, neglecting the fact that leukemia develops in only a fraction of radiologists, heavily exposed by occupation. Even in the Nagasaki and Hiroshima survivors the incidence of leukemia appears to have reached a low-level peak several years ago and to be decreasing at the present time.

4) We note with considerable satisfaction that the United Nations Scientific Committee is encouraging those nations within which there are regions of high natural radiation background to make intensive studies of these regions both from the standpoint of radiation measurement and from the standpoint of somatic and genetic effects in man and his living environment. We believe that epidemiologic and demographic studies of populations in the United States living under different conditions of radiation background are also feasible and desirable in spite of the obvious technical difficulties inherent in such studies at the low natural background levels of radiation.

5) With particular relation to Chapter V of the Report, we have the following comments related to specific points which are minor when weighed against the excellence of the Chapter as a whole.

a) Paragraphs 6 and 7: It would be helpful to define more clearly what is meant by "radio sensitivity."

b) Paragraph 11: We doubt that it is clearly established in man that there is evidence of a decline in resistance to radiation during senescence. The wording in paragraph 11 might be clarified in this regard.

c) Paragraph 18: The whole field of research with regard to the existence of specific toxic products induced in the blood by radiation is still controversial, and it is impossible to draw conclusions at the present time. We would have preferred it had the paragraph stated, "It has been suggested ..." rather than "There is some evidence ...".

d) Paragraph 19: We believe too great emphasis has been placed on blood supply alone with regard to the production of disturbances. Perhaps a more general way of stating the point would be to emphasize the inability of irradiated animals or tissues to react normally to homeostatic stimuli.

e) Paragraph 22: Most hematologists in this country are skeptical that a single dose of 250 mrem could produce a drop in lymphocytes. We consider it more likely that the reported drop in lymphocytes was produced not by radiation but by an alarm reaction (adrenal corticoids) produced by the conditions of the experiment.

f) Paragraph 29: This is so compactly written that it is difficult to follow. It is not clear what functional changes have been elicited with "often very low doses" and why they are of "great significance".

g) Paragraph 30: In this paragraph we note that "irradiation of animals with 300 to 400 r produces changes in the electroencephalogram of about one week's duration". In light of clinical experience further work is needed to establish the clinical significance of such exposures.

h) Paragraph 35: The sentence, "The sensitivity of the retina can be used as a detecting procedure of the effect of radiation upon the human body", is not clear.

i) Paragraph 36: It would have been helpful to mention the carcinomas of the accessory respiratory sinuses noted among some of the radium-dial painters. It would have been helpful to point out that little is known of the effects of radioactive particles in the lungs in comparison with the effects of internal emitters deposited elsewhere in the body. One of our subcommittees is preparing a report on inhalation hazards.

j) Paragraph 38: In the discussion of radioactive iodine, it is important that no parenchymatous tumors of the thyroid have yet developed in man in spite of very heavy doses of radiation from internal emitters to the thyroid. There is evidence that external radiation in childhood may later lead to the development of thyroid cancer.

k) Paragraph 58: It is inadvisable to use the rem as a unit to relate osteocyte dose to bone tumor incidence, since the Relative Biological Effectiveness for tumor induction is unknown.

l) Paragraph 65: We believe that there has not been precise wording of the statements, undoubtedly due to a desire to be as concise as possible. We would prefer to restate the paragraph as follows: Some tissues of the embryo and fetus are among the most easily destroyed by radiation. Malformations of a somatic type and other pathologic conditions have been observed in children exposed in utero to therapeutic radiation of their mothers. There is evidence that diagnostic exposure of the fetus may be associated with development of leukemia.

## Summary and Conclusions

We are in general accord with the report of the United Nations Scientific Committee on Effects of Atomic Radiation and read it with admiration for its quality and scope.

We hope that the Committee will issue supplemental reports from time to time, using the 1958 report as a point of departure.

December 13, 1958

Shields Warren, Chairman

Howard Andrews

John C. Bugher

Charles E. Dunlap

Webb Haymaker

Samuel P. Hicks

Harry Kornberg

Austin M. Brues, Rapporteur

Harry Blair

Eugene P. Cronkite

Jacob Furth

Louis H. Hempelmann

Henry S. Kaplan

Sidney Madden



MEDICAL RESEARCH COUNCIL

# Statement on the Report of the United Nations Scientific Committee on the Effects of Atomic Radiation

*Presented to Parliament by the Lord President of the Council  
by Command of Her Majesty  
August 1958*

LONDON

HER MAJESTY'S STATIONERY OFFICE

Medical Research Council,  
38 Old Queen Street,  
Westminster,  
London, S.W.1.

To the Right Honourable THE VISCOUNT HAILSHAM, O.C., *Lord President of the Council*

MY LORD,

In accordance with your request, the Medical Research Council asked their Committee which, in 1956, produced the report on The Hazards to Man of Nuclear and Allied Radiations, to prepare a statement on the report of the United Nations Scientific Committee on the Effects of Atomic Radiation. This they have now done and their statement has been accepted by the Medical Research Council who have authorised me to transmit it to you. Throughout the deliberations of the United Nations Scientific Committee, members of the Council's Committee and of the Council's staff have contributed both information and assessments of available data. When, therefore, my Council asked them to comment on the report of the United Nations Scientific Committee, they were already closely acquainted with much of the information and thought that it contained. In consequence they were able to produce their own statement with great expedition. Nevertheless, the Council recognise that this has required much anticipatory work and, since the report of the United Nations Scientific Committee became available, intensive consideration; and it is the Council's wish that, in transmitting this statement to you, I should express their appreciation of the way in which their Committee has carried out its task.

I have the honour to be, my Lord,

Your Lordship's obedient Servant,

LIMERICK, Chairman,  
Medical Research Council.

August, 1958

# MEDICAL RESEARCH COUNCIL

The Right Hon. the Earl of Limerick, GBE, KCB, DSO (*Chairman*)  
Sir Geoffrey Vickers, VC, MA (*Treasurer*)  
Richard Fort, BSc, MP  
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Professor C. H. Stuart-Harris, MD, FRCP  
Professor A. A. Miles, CBE, MD, FRCP  
Sir Harold Himsworth, KCB, MD, FRCP, FRS (*Secretary*)

## COMMITTEE APPOINTED BY THE MEDICAL RESEARCH COUNCIL TO REPORT ON THE HAZARDS TO MAN OF NUCLEAR AND ALLIED RADIATIONS

Sir Harold Himsworth, KCB, MD, FRCP, FRS (*Chairman*)  
Sir Ernest Rock Carling, FRCP, FRCS, FFR  
Sir John Cockcroft, OM, KCB, CBE, DSc, FRS  
Professor A. Haddow, MD, DSc, FRS  
Professor A. Bradford Hill, CBE, DSc, FRS  
J. F. Loutit, CBE, DM, FRCP  
Professor K. Mather, CBE, DSc, FRS  
Professor W. V. Mayneord, CBE, DSc, FInstP  
Professor P. B. Medawar, DSc, FRS  
Professor J. S. Mitchell, CBE, MB, MRCP, PhD, DMR, FFR, FRS  
Professor L. S. Penrose, MD, FRS  
E. E. Pochin, MD, FRCP  
Sir Edward Salisbury, CBE, DSc, FRS  
F. G. Spear, MD, DMRE, FFR  
Professor J. R. Squire, MD, FRCP  
A. C. Stevenson, MD, FRCP  
Professor C. H. Waddington, CBE, ScD, FRS  
Professor B. W. Windeyer, MB, MRCP, FRCS, DMRE, FFR  
W. G. Marley, OBE, PhD, attended by invitation.

Secretariat

Scientific Staff

Headquarters Staff

B. S. Lush, MD, MRCP

# THE REPORT OF THE SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION TO THE THIRTEENTH GENERAL ASSEMBLY OF THE UNITED NATIONS

## A REPORT TO THE MEDICAL RESEARCH COUNCIL BY THEIR COMMITTEE ON THE HAZARDS TO MAN OF NUCLEAR AND ALLIED RADIATIONS

1. In accordance with the request of the Lord President of the Council to the Medical Research Council, we have met and considered the Report of the United Nations Scientific Committee on the Effects of Atomic Radiation published on 10th August, 1958, and submit our comments herewith.

2. We would wish, at the outset, to offer our congratulations to the members of the United Nations Scientific Committee on having carried out so well the onerous task allotted to them. In our opinion their Report is both a valuable account of present knowledge in this field and an important contribution to the difficult problem of its assessment.

3. In general their Report follows the same lines as our own\* and that of the United States National Academy of Sciences†, both of which were published in June 1956; and we have derived considerable reassurance from the fact that, in a field of science that is so difficult and, as yet, relatively little developed, the three major reports on this subject are so substantially in agreement with each other. In the two years that have passed since our report was published much additional information has been collected, but this has led to no major revisions of opinion; rather it has strengthened and amplified the tentative conclusions and predictions in the two earlier reports.

In one respect, however, the report of the United Nations Committee has ranged more widely than either our own of 1956 or that of the United States National Academy of Sciences. Both these confined their attention to conditions in technologically well-developed countries of the Western world. The report of the United Nations Committee considers the problem on a world-wide basis.

4. In considering the Report we have departed from the arrangement of its chapters and to facilitate reference and comparison for readers in this country we have followed the sequence adopted in developing the subject in our own report of 1956. We have also felt it necessary to review first certain basic, although still uncertain, questions which inevitably influence the attitude towards the data subsequently considered.

5. The Annexes to the Report, containing as they do the detailed treatment of particular aspects, necessarily provide many examples of points on which, in the present state of our knowledge, differing opinions may justifiably be held. We have not, however, thought it profitable to set out such alternative views unless these affected a major conclusion or attitude adopted in the Report proper.

6. Finally, we wish to state that, throughout the deliberations of the United Nations Scientific Committee, many of our own members, and members of

\* The Hazards to Man of Nuclear and Allied Radiations (Cmd. 9780, H.M.S.O., 1956).

† The Biological Effects of Atomic Radiations Summary Reports (National Academy

the staff of the Medical Research Council, have provided the Committee with information and with assessments of particular aspects of the subject. We were, therefore, to some extent acquainted with the main trends of the Committee's thinking and this has expedited our consideration of their Report.

## The Fundamental Problem of the Relationship between Radiation Dose and the Effect which may be produced on Human Populations

7. Although there is as yet little direct information about the genetic effects of radiation on man, there is general agreement that the experimental evidence now available on animals and plants indicates that for every small increment of exposure to radiation there is a small but proportional increment in the frequency of mutations in the germ cells that will manifest themselves as genetic changes in future generations, and that there is no threshold dose below which no such effect occurs. This view—with which we agree—is the basis upon which the genetic hazard is discussed in the United Nations Committee's Report.

8. When the somatic effects of radiation are considered, however, scientific opinion is still divided as to whether a threshold dose exists below which there will be no induction of leukaemia or other form of cancer. This has been recognised by the United Nations Committee when for example in Table II, Chapter VII (Annexe II of this present report), they have calculated the casualties from leukaemia to be expected from exposure to radiation from estimated levels of fall-out. They conclude that, if a threshold does not exist, then a number of cases will be induced and that this number will be related to the average amount of radiation received by the population as a whole; if, on the other hand, a threshold does exist, and is at the level suggested, there will be none, unless by some special misfortune some individuals receive a dose of radiation greatly in excess of the average, when a small proportion of these might show ill effects.

9. Nevertheless, the impression that we have derived from reading Chapter IV of the Report on Fundamental Radiobiology, and more particularly Annexe F with the same title, is that there is a predisposition to favour the view that the induction by radiation of such possible long-term somatic effects as leukaemia and cancer is a process comparable to that of induction by radiation of genetic mutations, and that there is, in consequence, no threshold dose below which there is no induction of such somatic effects. In our opinion, this view tends to tinge the interpretation of subsequent data, despite the earlier recognition of the equally tenable alternative view.

10. In our view, it is not possible at this present time to decide whether there is or is not a threshold dose concerned in the induction of leukaemia and cancer, and the only scientific attitude to the problem at present is one of suspended judgment. Nevertheless the significance of the alternative points of view in determining the ultimate assessment of risk should be clearly understood so that those who have the responsibility for acting on such assessments should be fully aware of the alternative possibilities that need to be taken into account.

## The Effects of Radiation on the Health of the Individual (Somatic Effects)

11. We are in general agreement with the views expressed in Chapter V entitled "The Somatic Effects of Radiation". Apart from referring to the opinions we have expressed in the previous section on the present state of our knowledge regarding the induction of cancer and leukaemia by radiation, it will suffice if we indicate the relatively minor points upon which we have reservations.

12. We were surprised (para. 22 of Chapter V) to learn that a temporary drop in the level of white blood cells had been observed after a single dose of radiation as small as 250 mr. In our experience doses at least 50 to 100 times larger are required to produce unequivocal effects.

13. We have not ourselves observed the changes in function of the nervous system described as following small doses of radiation mentioned in paragraphs 29 and 30, and we are inclined to question the stress laid upon the role of small doses of irradiation in producing malformations of the brain and changes in retinal functions referred to in the latter half of paragraph 41.

14. In paragraph 32 of the Report the effects of radiation in producing temporary changes in fertility and causing permanent sterility are considered. It is not made clear, however, that the doses required to produce permanent sterility are very much larger than those which produce transient changes. Thus whilst it is said that a dose of 30r may produce transient changes in the male it is not made clear that the dose required to produce permanent sterility is in the region of 500r. In women a dose of 300r may be sufficient near the end of reproductive life, but considerably higher doses would be required earlier. If received in the course of whole body irradiation, doses of this magnitude would inevitably cause serious illness shortly after exposure.

15. According to our knowledge, the doses of radiation required to produce cataract, cited in paragraph 35, are unduly low even for minimal doses; nor are we aware of any published evidence that, in experimental animals, cataract formation has followed the administration of radiostrontium.

16. We note that reference is made to the survey of radiologists, carried out in this country, which does not confirm earlier reports that in persons so exposed to radiation there was a significant shortening of the life span (para. 51).

17. Although we are aware from animal experiments that resistance to the lethal effect of large doses of radiation decreases towards the end of the life-span, we know of no evidence that such an effect can be observed in man within the very wide dose range used in medical diagnostic and therapeutic radiology.

18. In paragraph 65, where the effect of radiation on the embryo and foetus are considered, the sentence occurs "Malformations and other pathological conditions have been observed following exposure of pregnant women to accidental and therapeutic irradiation and to diagnostic procedures, e.g. pelvimetry." In this form the sentence is unduly alarming. As far as we are aware, no evidence has been produced that the doses of radiation used in diagnostic procedures have produced congenital malformations in the child; and the evidence that the doses used in certain special examinations might very rarely result in a child so exposed later developing leukaemia can perhaps most fairly be assessed as a small possibility to be weighed against the importance of the need to carry out the particular examination.

#### The Genetic Effects of Radiation

19. As in the chapter on the somatic effects of radiation we are in substantial agreement with the views expressed in Chapter VI on genetic effects.

20. We accept the view given in paragraph 9 that the knowledge now available indicates that "there is at present no known threshold of radiation exposure below which genetic damage does not occur", that "the experi-

at moderate doses but is increasingly meagre at lower doses" and "that it is prudent to assume . . . as much hazard as is implied by a linear relation between mutation and gonad dose as has been done in the present [i.e., the United Nations Scientific Committee's] report."

21. We are pleased to note that, in the difficult matter of estimating the amount of radiation required to double the mutation rate of a representative number of human genes, the United Nations Scientific Committee have arrived at a range of possible values similar to that which we put forward. They suggest a range from 10 to 100 rad. In our report of 1956 we suggested a range of 30 to 80 rad.

22. In estimating the social burden that may be imposed upon populations by the presence of unfavourable genes, and the effects of increased exposure to radiation, the United Nations Scientific Committee have largely based their calculations upon recent work carried out in Northern Ireland. On this basis the conclusion is reached that a permanent doubling of the mutation rate might ultimately result in an increase in the present 4 per cent of live-born children with genetically determined disorders to some value greater than 5 per cent but less than 8 per cent.

In our own report of 1956, with the information available, we did not feel justified in dealing with this problem in this general way. Rather we chose to take conditions representative of different kinds of genetic disturbance and to show how the incidence of these would be altered by doubling the mutation rate; and by indicating the proportion of such conditions in the total of genetically determined disorders, and the wide differences in their importance both to the affected individual and to society, we tried to suggest broadly the scale of the problem.

The method adopted by the United Nations Scientific Committee has the advantage of indicating the overall size of the problem. The method we adopted has, on the other hand, the advantage of bringing out clearly the wide differences in the importance of different kinds of genetic disturbance and the time scale over which changes in incidence would occur in response to radiation. Following an increase in the mutation rate few generations are required for the increased incidence of deleterious dominant traits to reach its maximum; but a great number of generations and up to many hundreds of years are required for the maximal incidence of recessive traits or characteristics showing continuous variation about the average (biometrical characters) to become manifest.

Considering, however, the difficulty of this subject and the inadequacy of the data available, the two estimates are as much in accord as could reasonably be expected, and can be taken as a working basis for present purposes.

#### Existing and Foreseeable Levels of Exposure to Radiation

23. The important considerations under this heading are contained in Chapter III of the Report.

24. The assessment of doses received from the natural environment—the background radiation—agrees with that made by other authorities.

Although reference is made to the variation in the amount of background radiation in different areas of the world, and it is noted that in exceptional places the dose may be 10 times the world average, this point is not to be



lost sight of in subsequent chapters. As the amount of background radiation is taken as the standard with which to compare any increments of artificial radiation, the result is that, in places, the Report tends to lose perspective.

25. Both our report of 1956 and that of the United States National Academy of Sciences drew attention to the large contribution from medical diagnostic radiology to the genetically significant doses of radiation to the population. The American estimate was that this is equal in amount to the natural background. In this country we estimated that the contribution from it would be some 22 per cent of the natural background but made the reservation that this figure should be regarded as tentative and probably a lower limit. Further information has confirmed us in this reservation so that we are now willing to accept that the genetically significant dose from this source may be as much as 100 per cent of the natural background radiation in countries with extensive medical facilities. Although the world average may eventually rise to the figure quoted, at the present time it must be very much lower because there are large populations in which radiological examinations are very infrequent.

It is reassuring to note, however, that there is agreement that most of this genetically significant radiation comes from a few types of radiological examinations.

26. An estimate has been made, on the basis of recent figures from the United States, of the contribution from radiotherapy to the average quantity of radiation received by individuals in a population where there are extensive medical facilities. The average contribution from this source to the bone marrow is thought to be of the order of 10 to 20 per cent of the average that would be received from diagnostic procedures; to the genetically significant dose the contribution is somewhat less.

27. The estimates of exposure from industry, research and other minor sources of radiation are in satisfactory and reassuring agreement with previous estimates. Although giving no present cause for concern, the potential hazards from radioactive wastes are recognised.

28. In respect of environmental contamination from radioactive fall-out following nuclear weapon tests, attention is concentrated on fission products, although the production of some radioactive isotopes by neutrons is noted.

29. In 1956, when we produced our own report, attention was concentrated on the reservoir of fission products in the stratosphere. It is now recognised that the deposition from this reservoir is not uniform over the globe but that countries between 30° and 50° North may receive a deposition about three times greater than the world-wide average. Further, it is known that some of the fission products from nuclear explosions do not reach the upper atmosphere (the stratosphere) but descend relatively rapidly from the lower atmosphere (the troposphere). In some countries tropospheric fall-out also increases the deposition of long-lived isotopes, like strontium 90, by about 10 per cent above that from stratospheric fall-out alone.

30. As was to be expected from the steady fall-out of radioactive isotopes, the cumulative amounts on the earth's surface are increasing. The rate of increase varies from place to place according to the influence of such factors as geographical position and meteorological conditions. In this country since 1954 the fall-out rate of strontium 90 has increased very little, from 2 to 2.5 mc/Km<sup>2</sup> yearly; in New York State the increase has been from 3 to about 4.5 mc/Km<sup>2</sup>.

31. In our report of 1956 we estimated that, if nuclear weapons of the type then in use continued to be exploded indefinitely at the same rate as over the previous few years, then, when equilibrium was reached in about 100 years' time, the dose to the reproductive organs from external radiation in the United Kingdom would be about 0.026 r. over any subsequent 30-year period. But at about the time we published our report, radioactive caesium from fall-out was detected in the human body. From a biological point of view radioactive caesium resembles the naturally occurring radioactive potassium which contaminates ordinary potassium and which, like it, is distributed throughout the body including the reproductive organs. Further, it has since been found that the average time during which radioactive caesium is retained in the human body is some 7 times longer than was then believed. The United Nations Scientific Committee have taken these facts into account. They have also used a factor for shielding and weathering thought to be more representative for the world as a whole and allowed for a greater contribution from tropospheric fall-out. These considerations have led them to an estimate that, over a period of 30 years, the upper limit for the genetically significant dose to the reproductive organs could be 0.06 rem or 0.12 rem according to which of the two assumptions mentioned in para. 35 below for estimating future levels of fall-out is chosen.

We accept these values but would point out that to appreciate their significance they should be considered against the dose of 3 rem given in the same Table, which would, on the average, be received from the natural background radiation over the same period.

32. As we stated at the outset we, in our report in 1956, had confined our attention to conditions in countries comparable to the United Kingdom. The United Nations Scientific Committee have considered the problem on a world-wide basis, and have, therefore, taken into account the effect of differences in type of diet upon the concentration of strontium 90 in bone.

33. The harmful effects ascribed to strontium 90 are related to its concentration in the skeleton. This concentration is expressed as the ratio between strontium 90 and calcium in bone\*. Both strontium 90 and calcium enter the body in food, and the concentration of strontium 90 in bone depends both on the amount of strontium 90 and on the amount of calcium in the particular diet.

In Western diets, milk is the predominant source of both strontium 90 and calcium. Here the cow is, as it were, interposed as a partial filter between vegetation, which is contaminated with strontium 90, and the human body. In countries where the diet is predominantly derived from plants, as in countries where rice is a staple food, there is no such filter between man and his environment. As a result, for the same degree of fall-out, higher concentrations of strontium 90 would be expected in the bones of those living on mainly plant-type diets than in the bones of those living on milk-type diets.

Complications, such as differing soil composition and agricultural practice, also enter into this problem. Taking all considerations together the United Nations Scientific Committee conclude that, for the same degree of fall-out, the average concentration of strontium 90 in the bones of those living on a plant-type diet may be up to 5 or 6 times that in the bones of those on a milk-type diet.

We consider that, on the available evidence, this is a reasonable conclusion.

\* The unit used in this measurement is the Strontium Unit or S.U.

1 S.U. = 1.11 µCi (1.11 microcuries) of strontium 90 per gramme of calcium.

34. Dietary habit also influences the amount of caesium 137 taken into the body. The upper limit, however, would be most unlikely to be as much as twice the average value.

35. The Report is concerned not only with present levels of fall-out, but with those that might occur in the future.

It is a comparatively easy matter to calculate with some assurance the levels of fall-out that will occur in the future as a result of explosions that have already happened. It is an entirely different matter to calculate the levels that might occur from future testing. To do this, it would be necessary to know the testing programme and foresee the design of future weapons. If, therefore, the United Nations Scientific Committee were to give some idea of what continuing testing would entail, they had perforce to make particular assumptions. They chose to make two alternative assumptions and on the basis of these constructed two different models of the degree and rate of fall-out.

The first assumption (model "a" in Table I of Chapter VII which is here reproduced as Annexe I) is that the future rate at which fission products are injected into the stratosphere will be such as to maintain the fall-out rate constant at the present level. Implicit in this assumption is the idea that the unusually heavy explosions in the spring of 1954 injected a "bank" of fission products into the stratosphere and that subsequent explosions have been no more than would suffice to keep this "topped up".

The second assumption (model "b", Table I, Chapter VII, here reproduced as Annexe I) is that weapon tests, equivalent in release and injection of fission products into the stratosphere to the whole sequence of weapon tests from the beginning of 1954 to the end of 1958, will continue to be repeated at a constant rate. Under this assumption the heavy tests in the spring of 1954 are included.

When, in about 100 years' time, equilibrium is expected to have been reached between new fission products injected and the decay of those already there, and, in consequence, the radioactivity in the stratosphere is maintained at a constant level, the value given by assumption "b" is about twice as large as that given by assumption "a".

36. We have carefully considered these calculations. The method chosen for their working out seems to us reasonable but the soundness of the conclusions reached necessarily depends on the validity of the initial assumptions.

#### Assessment of the Hazards of Exposure to Radiation

37. Consideration of this aspect of the subject is brought together in Chapter VII of the Report, entitled "Summary and Recommendations". For convenience of reference we have reproduced Tables I and II from this Chapter as Annexes I and II of this report.

38. Table I summarises the estimated doses from radioactive sources, and we have the following comments to make upon it.

39. *Natural sources.* The figures given opposite this heading are computed from the world-wide averages. Owing to the variation in the natural background from place to place, we feel that the significance of the other data in the table could have been better appreciated if the range of variation in

40. *Man-made sources (except environmental contamination and occupational exposure).* These make easily the largest contribution to the genetically significant dose, and medical diagnostic radiology is by far the most important single source. The figures given are those for countries with extensive medical facilities. As a world-wide figure they must, therefore, be regarded as something that may occur in the future rather than something that exists at present.

41. *Occupational exposure.* These figures are accepted and it is gratifying to see that the risk from this source is being maintained at such a low level.

42. *Weapon tests, ceasing at end of 1958.* We accept these figures as reasonable approximations.

The mean marrow dose under this cross-heading is attributable in large part to strontium 90 in bone. Translating the figures for exposure from rems to strontium units yields values of 2.3 S.U. as the average level in human bone of populations on a milk-type diet, 14 S.U. as the average in those on a plant-type diet, in both cases as the average over the forthcoming 70 years.

In our report of 1956, we said that the maximum allowable concentration of strontium 90 in the bones of the general population, with its proportion of young children, should not be greater than 100 S.U. This level had been adopted by the International Commission on Radiological Protection and was allowed in the Report of the United States National Academy of Sciences. The special sub-committee of the United States National Academy of Sciences appointed to consider this matter were unable to reach agreement, but the general belief was that 50 S.U. would produce no perceptible effect; we felt that immediate consideration would be required if the level in the general population showed signs of rising greatly above 10 S.U.

43. *Weapon tests continued until equilibrium is reached in about 100 years.* These figures are based upon the alternative assumptions set out in paragraph 35 of our present report. In so far as these assumptions are valid, the figures are in our view reasonable. Translating the marrow doses from rems to equivalent average concentration of strontium 90 in bone, the figures for countries on a milk-type diet become under assumption 'a', 19 S.U., and under assumption 'b', 40 S.U.; for countries on a plant-type diet under assumption 'a', 107 S.U., and under assumption 'b', 240 S.U.

44. Because of the view that there is no threshold dose of radiation below which genetic mutations do not occur, and because the relation between dose of radiation and incidence of mutations is thought to be linear, it is justifiable to accept the figures in Table I under the heading of "Genetically significant dose" as indicative of the degree of genetic damage that might occur from each of the different sources of radioactivity mentioned. Whether or not the figures under the heading "Per capita mean marrow dose" are accepted as indicating the degree of risk in respect of the induction of leukaemia or bone tumours depends upon the view taken with regard to the existence of a threshold dose of radiation below which no such induction takes place. If no threshold exists then these estimates of exposure indicate the risk involved. If, on the other hand, a threshold does exist, then no risk would occur until the exposure exceeded its value. In the present state of knowledge it is not possible to decide between these alternatives.

45. In Table II are given the United Nations Committee's estimates of the possible annual incidence of casualties in the world population which might develop as a consequence of radiation from fallout. In making these

calculations they have accepted the view that there is no threshold dose for genetic changes but, being unable to decide whether a threshold dose exists for somatic changes such as leukaemia, they give estimates based on both the alternative views.

46. It will be noted that the United Nations Committee consider that only a fraction of the naturally occurring genetic defects, or cases of leukaemia or bone tumour, could be due to radiation from the natural background. We agree with this view and accept that the estimates of the fractions so caused are reasonable according to present information. The ratio between the number of cases estimated to be due to natural radiation and the estimated number of those that may be caused by fall-out gives a measure of the relative importance of these two sources of radiation exposure in causing the particular genetic and somatic effects.

47. When we reported in 1956 we did not consider that the state of knowledge at that time justified our attempting to estimate the numbers of persons who might be affected by radiation from any source. Since then more knowledge has become available on the relation between large doses of radiation and the incidence of leukaemia. Nevertheless we would still hesitate to make estimates of the numbers in a population who might be affected. On the other hand, we appreciate that many such estimates have been made and that the United Nations Scientific Committee could not ignore them. In these circumstances it was inevitable that they should attempt to make their own estimates, although, in so doing, they were very conscious of the many uncertainties and unproved assumptions that were involved [Annexes D and G]. After careful consideration of the estimates given in Table II, it is our opinion that the concepts on which these are based are not unreasonable, and we think that any other equally well-informed body of scientists would be unlikely to make estimates which fall outside the limits given.

48. In conclusion we would emphasise again our respect for the achievement of the United Nations Scientific Committee in producing this Report. Our task having been to comment on their Report, we have necessarily tended to pay more attention to points of difference than to points of agreement. This should not, however, obscure the fact that we are in no disagreement with them on any major piece of information or concept. When we do differ we do so only on questions of emphasis and the choice of the most probable values within the wide latitude of possibilities that are left open to us by the insufficiency of our knowledge in this field.

Signed on behalf of the Committee,

H. P. HIMSWORTH, *Chairman*.

# ANNEXE I

TABLE I. ESTIMATED DOSE FROM DIFFERENT RADIOACTIVE SOURCES  
(Computed from world-wide averages)

| Source                                                                                                    | Genetically significant dose<br>Maximum for any<br>30-year period (rem) <sup>a</sup> | Per capita mean marrow dose<br>Maximum for any<br>70-year period (rem) <sup>b</sup>            |
|-----------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
| Natural sources ...                                                                                       | 3                                                                                    | 7                                                                                              |
| Man-made sources (except<br>environmental contamination<br>and occupational<br>exposure) <sup>a</sup> ... | 0.5-5                                                                                | Ranges beyond 7                                                                                |
| Occupational exposure <sup>b</sup> ...                                                                    | Less than 0.06                                                                       | 0.1-0.2                                                                                        |
| Environmental<br>contamination<br>(hypothetical cases) <sup>c, d</sup>                                    |                                                                                      | Estimates for<br>countries<br>deriving most<br>of dietary<br>calcium from<br>milk <sup>e</sup> |
| Weapon tests cease at end<br>of 1958 ...                                                                  | 0.010                                                                                | 0.16                                                                                           |
|                                                                                                           |                                                                                      | Estimates for<br>countries<br>deriving most<br>of dietary<br>calcium from<br>rice <sup>e</sup> |
|                                                                                                           |                                                                                      | 0.96                                                                                           |
| Weapon tests continue until<br>equilibrium is reached in<br>about a hundred years <sup>f</sup> ...        | 0.060                                                                                | 0.12                                                                                           |
|                                                                                                           | 1.3                                                                                  | 2.8                                                                                            |
|                                                                                                           | 7.5                                                                                  | 17                                                                                             |
|                                                                                                           | Estimated percentages of the maximum doses for<br>continued weapon tests             |                                                                                                |
|                                                                                                           | Assump-<br>tion a <sup>f</sup>                                                       | Assump-<br>tion b <sup>f</sup>                                                                 |
| Weapon tests cease                                                                                        |                                                                                      |                                                                                                |
| 1958 ...                                                                                                  | 17                                                                                   | 9                                                                                              |
| 1968 ...                                                                                                  | 42                                                                                   | 33                                                                                             |
| 1978 ...                                                                                                  | 64                                                                                   | 56                                                                                             |
| 1988 ...                                                                                                  | 79                                                                                   | 67                                                                                             |
| Weapon tests continue ...                                                                                 | 100                                                                                  | 100                                                                                            |

<sup>a</sup> For countries having an extensive use of the radiation sources listed and reporting data to the Committee.

<sup>b</sup> Doses for certain technologically highly developed countries only.

<sup>c</sup> Computed from population weighted world-wide average of stratospheric fall-out rate and deposit.

<sup>d</sup> Regional values may differ by a factor of about  $\frac{1}{2}$  to 2 from the estimated population weighted world-wide average values because of the latitudinal variation of fall-out rate and deposit. In some areas of the world the tropospheric fall-out may tend to raise the upper limit of this range, especially in the vicinity of test sites.

<sup>e</sup> The extent to which these estimates apply to populations of different dietary habits and to those living in areas of differing soil conditions is discussed in paragraph 69 of chapter III.

<sup>f</sup> Assumption a is that the injection rate is such as to maintain a constant fall-out rate of strontium-90 and caesium-137, whereas assumption b is that weapon tests equivalent in release and stratospheric injection of fission products to the whole sequence of weapon tests from the beginning of 1954 to the end of 1958 will be repeated at constant rate. This second assumption will give an equilibrium value for the fall-out rate and deposit approximately a factor of 2 higher than that calculated by using the first assumption.

## ANNEXE II

TABLE II. ESTIMATES OF CERTAIN POSSIBLE ANNUAL CONSEQUENCES OF RADIATION RECEIVED BY WORLD POPULATION FROM CERTAIN SOURCES

| Consequence                               | World population assumed (in millions) | Natural occurrence assumed per year | Source of radiation                |                                |                                                      |
|-------------------------------------------|----------------------------------------|-------------------------------------|------------------------------------|--------------------------------|------------------------------------------------------|
|                                           |                                        |                                     | Natural radiation                  | Fall-out from weapon tests     |                                                      |
|                                           |                                        |                                     |                                    | Tests stopping in 1958         | In equilibrium after prolonged continuation of tests |
| <i>Leukemia</i>                           |                                        |                                     |                                    |                                |                                                      |
| If threshold 0 rem ...                    | { 3,000<br>5,000                       | { 150,000<br>250,000                | { 15,000<br>25,000                 | 400 to 2,000 <sup>a</sup><br>— | —<br>5,000 to 60,000                                 |
| If threshold 400 rem                      | { 3,000<br>5,000                       | { 150,000<br>250,000                | { 0 <sup>b</sup><br>0 <sup>b</sup> | { 0 <sup>c</sup><br>—          | —<br>0 <sup>d</sup>                                  |
| <i>Major Genetic Defects</i> <sup>a</sup> | 5,000                                  | 700,000 to 3,000,000                | 25,000 to 1,000,000                | <sup>e</sup>                   | 500 to 40,000                                        |

<sup>a</sup> Maximum rate during peak period. An estimated total of less than 25,000 to 150,000 would ultimately occur.

<sup>b</sup> Unless individual bone marrow dose exceeds mean value by a factor of 60.

<sup>c</sup> Unless individual bone marrow dose exceeds mean value by a factor of 80 to 500.

<sup>d</sup> Unless individual bone marrow dose exceeds mean value by a factor of 5 to 60.

<sup>e</sup> Conditions which are at least a serious handicap to those affected, as listed in table XI of annex H.

<sup>f</sup> A total of 2,500 to 100,000 would occur over subsequent years.

Notes.—The methods of estimating incidences of leukemia and major genetic defects are described in annex D, paras. 127 to 130.

The quantitative evaluation of an increase in incidence of primary bone tumour attributable to radiation presents great difficulties. If it were assumed that 5 to 10 cases per million normally occurred per year, and that 10 per cent. of these were induced by natural radiation the following figures could be calculated from the 70-year osteocyte doses if a non-threshold hypothesis were assumed:

For tests stopping in 1958 and world population 3,000 million, 70 to 900 per year (as the maximum rate).

In equilibrium after prolonged continuation of tests and world population 5,000 million, 1,000 to 25,000 per year (as the continuing rate).

If a threshold of 400 rem were assumed, the incidences would be zero unless individual osteocyte doses exceeded the mean value by a factor of 80 to 500 in the case of tests stopping in 1958 and by a factor of 5 to 60 in equilibrium after prolonged continuation of tests.

## APPENDIX I

## ANNOUNCED NUCLEAR DETONATIONS

United States  
United Kingdom  
Union of Soviet Socialist Republics

Compiled  
by  
Kosta Telegadas

Special Projects Section  
Office of Meteorological Research  
U. S. Weather Bureau  
Washington, D. C.  
November, 1959

9. Remarks ----- Other pertinent information. In several cases, the AEC press release for Soviet detonations was in the form of a statement on a particular date by a U. S. official which does not necessarily mean that the detonation occurred on that date.

Safety experiments were conducted from time to time at the Nevada Test Site to determine the nuclear safety of weapons in case of accident. As of October 30, 1958, 32 such experiments were held in Nevada. Of these, it has been confirmed that 17 resulted in very low, but measurable nuclear yield. A safety experiment which resulted in very low, but measurable, nuclear yield has been included as a nuclear detonation and therefore, the number of U. S. detonations presented here will be higher than that officially released by the Atomic Energy Commission.

SUMMARY OF U. S. NUCLEAR DETONATIONS

|      |          |                                     | Number | Cumulative |
|------|----------|-------------------------------------|--------|------------|
| 1945 | July     | Trinity Site, New Mexico            | 1      | 1          |
|      | August   | Japan                               | 2      | 3          |
| 1946 | July     | Crossroads, Bikini Atoll            | 2      | 5          |
| 1948 | April    | Sandstone, Eniwetok Proving Grounds | 3      | 8          |
| 1951 | Jan-Feb  | Ranger, Nevada Test Site            | 5      | 13         |
|      | Apr-May  | Greenhouse, Eniwetok, P.G.          | 4      | 17         |
|      | Oct-Nov  | Buster-Jangle, Nevada T.S.          | 7      | 24         |
| 1952 | Apr-June | Tumbler-Snapper, Nevada T.S.        | 8      | 32         |
|      | Nov.     | Ivy, Eniwetok P.G.                  | 2      | 34         |
| 1953 | Mar-June | Upshot-Knothole, Nevada T.S.        | 11     | 45         |
| 1954 | Mar-May  | Castle, Eniwetok P.G.               | 6      | 51         |
| 1955 | Feb-May  | Teapot, Nevada T.S.                 | 14     | 65         |
|      | May      | Wigwag, Pacific Ocean               | 1      | 66         |
| 1956 | Jan      | Safety, Nevada T.S.                 | 1*     | 67         |
|      | May-July | Redwing, Eniwetok P.G.              | 6**    | 73         |
| 1957 | May-Oct  | Plumbbob, Nevada T.S.               | 26*    | 99         |
|      | Dec      | Safety, Nevada T.S.                 | 2*     | 101        |
| 1958 | Apr-Aug  | Hardtack, Eniwetok P.G.             | 16**   | 117        |
|      | Sept-Oct | Hardtack Phase II, Nevada T.S.      | 31*    | 148        |
|      | Aug-Sept | Argus, South Atlantic               | 3      | 151        |

\* Safety Experiments at the Nevada Test Site which resulted in very low, but measurable, nuclear yield are included.

\*\* Additional detonations occurred in the Redwing and Hardtack Test Series which have not been announced.

SUMMARY OF U. K. NUCLEAR DETONATIONS

|      |            |                                                       |   |    |
|------|------------|-------------------------------------------------------|---|----|
| 1952 | Oct        | Hurricane, Monte Bello Islands A.S.                   | 1 | 1  |
| 1953 | Oct        | Totem, Woomera, Australia                             | 2 | 3  |
| 1956 | May-June   | Mosaic, Monte Bello Islands                           | 2 | 5  |
|      | Sept-Oct   | Buffalo, Maralinga Proving Grounds<br>South Australia | 4 | 9  |
| 1957 | May-June   | Grapple, Christmas Island, Pacific                    | 3 | 12 |
|      | Sept-Oct   | Antler, Maralinga, P.G., S. Australia                 | 3 | 15 |
|      | Nov        | Grapple, Christmas Island, Pacific                    | 1 | 16 |
| 1958 | April-Sept | Grapple, Christmas Island, Pacific                    | 5 | 21 |



SUMMARY OF USSR NUCLEAR DETONATIONS

|      |           | Number | Cumulative |
|------|-----------|--------|------------|
| 1949 | September | 1      | 1          |
| 1951 | October   | 2      | 3          |
| 1953 | August    | 2*     | 5          |
| 1954 | October   | 1*     | 6          |
| 1955 | Aug-Nov   | 4*     | 10         |
| 1956 | Mar-April | 2*     | 12         |
|      | Aug-Nov   | 5*     | 17         |
| 1957 | Jan-Apr   | 7*     | 24         |
|      | Aug-Dec   | 6      | 30         |
| 1958 | Feb-Mar   | 9      | 39         |
|      | Sept-Nov  | 16     | 55         |

\*Announced by U. S. as being part of a series

U. S. NUCLEAR DETONATIONS

| No.       | Date    | Time Local | Name    | Type                | Yield             | Cloud-Height (ft.) | Location          | Remarks                                         |
|-----------|---------|------------|---------|---------------------|-------------------|--------------------|-------------------|-------------------------------------------------|
| 1945<br>1 | 15 JULY | 0530 MDT   |         | 100 ft tower        | nominal           | 35,000             | Alamogordo, N. M. | First test of A-bomb.                           |
| 1         | 16 AUG. | 0815       |         | air burst           | nominal           |                    | Hiroshima, Japan  | Detonated about 1,550 ft above surface.         |
| 2         | 9 AUG.  | 1048       |         | air burst           | nominal           |                    | Nagasaki, Japan   | Detonated about 1,550 ft above surface.         |
| 1946<br>1 | 1 JULY  | 0901       | Able    | air drop            | nominal           | about 35,000       | Bikini            | Detonated 518 feet above surface of the lagoon. |
| 2         | 25 JULY | 0835       | Baker   | shallow under water | nominal           | 10,000             | Bikini            | Detonated 90 feet below water surface.          |
| 1946<br>1 | 15 AUG. | 0617       | Kew     | 200 ft tower        |                   | 55,000             | Bikini            |                                                 |
| 2         | 1 MAY   | 0609       | Yoda    | 200 ft tower        |                   | 55,000             | Bikini            |                                                 |
| 3         | 15 MAY  | 0604       | Zebra   | 200 ft tower        |                   | 28,500             | Bikini            |                                                 |
| 1947<br>1 | 27 JAN. | 0945 PBT   | Able    | air burst           | low kiloton range | 17,000             | Bikini            |                                                 |
| 2         | 28 JAN. | 0950 PBT   | Baker   | air burst           | low kiloton range | 35,000             | Bikini            |                                                 |
| 3         | 1 FEB.  | 0615 PBT   | Baker   | air burst           | low kiloton range | 12,000             | Bikini            |                                                 |
| 4         | 2 FEB.  | 0945 PBT   | Baker-2 | air burst           | low kiloton range | 35,000             | Bikini            |                                                 |
| 5         | 6 FEB.  | 0947 PBT   | Fox     | air burst           | kiloton range     | 40,000             | Bikini            |                                                 |
| 1948<br>1 | 1 APRIL |            | Dag     | 300 ft tower        |                   |                    | Bikini            |                                                 |
| 2         | 2 APRIL |            | Baker   | 300 ft tower        |                   |                    | Bikini            |                                                 |
| 3         | 3 APRIL |            | George  | 200 ft tower        |                   |                    | Bikini            |                                                 |
| 4         | 4 APRIL |            | Item    | 200 ft tower        |                   |                    | Bikini            |                                                 |
| 1949<br>1 | 22 OCT. |            | Able    | 100 ft tower        |                   |                    | Bikini            |                                                 |
| 2         | 28 OCT. |            | Baker   | air                 |                   |                    | Bikini            |                                                 |
| 3         | 30 OCT. |            | Charlie | air                 |                   |                    | Bikini            |                                                 |
| 4         | 1 NOV.  |            | Dag     | air                 |                   |                    | Bikini            |                                                 |
| 5         | 5 NOV.  |            | Baker   | surface             | 1.2 KT            |                    | Bikini            |                                                 |
| 6         | 19 NOV. |            | Super   | underground         | 1.2 KT            |                    | Bikini            |                                                 |
| 7         | 29 NOV. |            | Quile   |                     |                   |                    | Bikini            |                                                 |

17 ft. below surface.

## U. S. NUCLEAR DETONATIONS

| No.                    | Date    | Time<br>Local | Name    | Type         | Yield         | Cloud-Height<br>(MSL - feet) | Location | Remarks                                |
|------------------------|---------|---------------|---------|--------------|---------------|------------------------------|----------|----------------------------------------|
| <b>1952</b>            |         |               |         |              |               |                              |          |                                        |
| <b>TUMBLER-SHAPPER</b> |         |               |         |              |               |                              |          |                                        |
| 1                      | 1 Apr.  | 0900 PST      | Able    | 500 ft air   |               | 16,000                       | Nevada   |                                        |
| 2                      | 15 Apr. | 0930 PST      | Baker   | 1,350 ft air |               | 16,000                       | Nevada   |                                        |
| 3                      | 22 Apr. | 0930 PST      | Charlie | 3,450 ft air |               | 42,000                       | Nevada   |                                        |
| 4                      | 1 May   | 0930 PST      | Dog     | 1,050 ft air |               | 44,000                       | Nevada   |                                        |
| 5                      | 7 May   | 0515 PST      | Easy    | 300 ft tower | 13 KT         | 34,000                       | Nevada   |                                        |
| 6                      | 25 May  | 0500 PST      | Fox     | 300 ft tower | 11.9 KT       | 41,000                       | Nevada   |                                        |
| 7                      | 1 June  | 0455 PST      | George  | 300 ft tower | 17.0 KT       | 37,000                       | Nevada   |                                        |
| 8                      | 5 June  | 0455 PST      | How     | 300 ft tower | 17.6 KT       | 42,000                       | Nevada   |                                        |
| <b>IVY</b>             |         |               |         |              |               |                              |          |                                        |
| 1                      | 1 Nov.  | 0715          | Mike    | surface      | hydrogen bomb | about 130,000                | Eniwetok |                                        |
| 2                      | 16 Nov. | 1130          | King    | air drop     | high yield    | 75,000                       | Eniwetok |                                        |
| <b>1953</b>            |         |               |         |              |               |                              |          |                                        |
| <b>UPSHOT-KNOTHOLE</b> |         |               |         |              |               |                              |          |                                        |
| 1                      | 17 Mar. | 0520 PST      | Annie   | 300 ft tower | 17.7 KT       | 41,000                       | Nevada   |                                        |
| 2                      | 24 Mar. | 0510 PST      | Maury   | 300 ft tower | 28.3 KT       | 41,000                       | Nevada   |                                        |
| 3                      | 31 Mar. | 0500 PST      | Ruth    | 300 ft tower | 0.21KT        | 14,300                       | Nevada   |                                        |
| 4                      | 6 Apr.  | 0730 PST      | Dixie   | 6,020 ft air | 10.8 KT       | 43,000                       | Nevada   |                                        |
| 5                      | 11 Apr. | 0445 PST      | Ray     | 100 ft tower | 2.22KT        | 14,000                       | Nevada   |                                        |
| 6                      | 18 Apr. | 0435 PST      | Badger  | 300 ft tower | 28.8 KT       | 37,200                       | Nevada   |                                        |
| 7                      | 25 Apr. | 0430 PST      | Slimon  | 300 ft tower | 52.0 KT       | 43,200                       | Nevada   |                                        |
| 8                      | 8 May   | 0730 PST      | Enoree  | 2,423 ft air | 26.4 KT       | 40,500                       | Nevada   |                                        |
| 9                      | 19 May  | 0405 PST      | Harry   | 300 ft tower | 32.1 KT       | 44,200                       | Nevada   |                                        |
| 10                     | 25 May  | 0730 PST      | Grable  | 280 mm gun   |               |                              | Nevada   |                                        |
| 11                     | 4 June  | 0315 PST      | Climax  | 1,334 ft air | 60.0 KT       | 41,700                       | Nevada   |                                        |
| <b>1954</b>            |         |               |         |              |               |                              |          |                                        |
| <b>CASTLE</b>          |         |               |         |              |               |                              |          |                                        |
| 1                      | 1 Mar.  | 0645          | Bravo   | ground       | 15 MT         | over 100,000                 | Bikini   | Experimental thermo-nuclear device.    |
| 2                      | 27 Mar. | 0630          | Romeo   | barge        |               |                              | Bikini   |                                        |
| 3                      | 7 Apr.  | 0620          | Koon    | ground       |               |                              | Bikini   |                                        |
| 4                      | 26 Apr. | 0610          | Union   | barge        |               |                              | Bikini   |                                        |
| 5                      | 5 May   | 0610          | Yankee  | barge        |               |                              | Bikini   |                                        |
| 6                      | 14 May  | 0620          | Hector  | barge        |               |                              | Eniwetok |                                        |
| <b>1955</b>            |         |               |         |              |               |                              |          |                                        |
| <b>TEAPOT</b>          |         |               |         |              |               |                              |          |                                        |
| 1                      | 15 Feb. | 1200 PST      | Wasp    | low air      |               | 20,000                       | Nevada   | Detonated at 762 ft above the surface. |
| 2                      | 22 Feb. | 0545 PST      | Moth    | 300 ft tower |               | 24,500                       | Nevada   |                                        |
| 3                      | 1 Mar.  | 0530 PST      | Tesla   | 300 ft tower |               | 30,000                       | Nevada   |                                        |
| 4                      | 7 Mar.  | 0520 PST      | Turk    | 300 ft tower |               | 45,000                       | Nevada   |                                        |
| 5                      | 12 Mar. | 0520 PST      | Sorpat  | 300 ft tower |               | 37,000                       | Nevada   |                                        |
| 6                      | 22 Mar. | 0505 PST      | See     | 500 ft tower |               | 39,500                       | Nevada   |                                        |
| 7                      | 23 Mar. | 1230 PST      | Eze     | underground  | 1.2 KT        | 12,000                       | Nevada   | 67 ft below surface.                   |

## U. S. NUCLEAR DETONATIONS

| No.             | Date    | Time<br>Local | Name       | Type               | Yield                 | Cloud-Height<br>(MSL - feet) | Location      | Remarks                                                    |
|-----------------|---------|---------------|------------|--------------------|-----------------------|------------------------------|---------------|------------------------------------------------------------|
| <b>1956</b>     |         |               |            |                    |                       |                              |               |                                                            |
| 8               | 29 Mar. | 0455 PST      | Apple      | 500 ft tower       |                       | 32,000                       | Nevada        |                                                            |
| 9               | 29 Mar. | 1000 PST      | Wasp Prime | 750 ft air         |                       | 31,500                       | Nevada        |                                                            |
| 10              | 6 Apr.  | 1000 PST      | SA         | high air           | few KT                | 55,000                       | Nevada        | Detonated at an altitude of 36,520 ft. MSL.                |
| 11              | 9 Apr.  | 0430 PST      | Post       | 300 ft tower       |                       | 15,500                       | Nevada        |                                                            |
| 12              | 15 Apr. | 1115 PST      | Met        | 400 ft tower       |                       | 41,500                       | Nevada        |                                                            |
| 13              | 5 May   | 0510 PST      | Apple Two  | 500 ft tower       | 30 KT                 | 43,000                       | Nevada        |                                                            |
| 14              | 15 May  | 0500 PST      | Zucchini   | 500 ft tower       |                       | 36,000                       | Nevada        |                                                            |
| 1               | 17 May  |               |            | underwater         |                       |                              | Pacific Ocean | Off west coast of the U.S.                                 |
| <b>1956</b>     |         |               |            |                    |                       |                              |               |                                                            |
| <b>SAFETY</b>   |         |               |            |                    |                       |                              |               |                                                            |
| 1               | 10 Jan. | 1300 PST      |            | surface            | safety                |                              | Nevada        | Slight nuclear yield.                                      |
| <b>1956</b>     |         |               |            |                    |                       |                              |               |                                                            |
| <b>REDWING</b>  |         |               |            |                    |                       |                              |               |                                                            |
| 1               | 5 May   | 0625          | Lacrosse   | surface            | kiloton range         |                              | Eniwetok      |                                                            |
| 2               | 21 May  | 0551          | Cherokee   | air drop           | several megatons      |                              | Bikini        | First H-Bomb air drop by U.S.                              |
| 3               | 28 May  | 0556          | Zuni       | ground             |                       |                              | Bikini        |                                                            |
| 4               | 9 July  | 0606          | Apache     | barge              |                       |                              | Eniwetok      |                                                            |
| 5               | 11 July | 0556          | Navajo     | barge              |                       |                              | Bikini        |                                                            |
| 6               | 21 July | 0546          | Tewa       | barge              |                       |                              | Bikini        |                                                            |
|                 | 23 July |               |            |                    |                       |                              |               | Statement on conclusion of Operation Redwing.              |
| <b>1957</b>     |         |               |            |                    |                       |                              |               |                                                            |
| <b>FLINGBOB</b> |         |               |            |                    |                       |                              |               |                                                            |
| 1               | 28 May  | 0445 PDT      | Baltamann  | 500 ft tower       | about half nominal    | 33,000                       | Nevada        |                                                            |
| 2               | 2 June  | 0455 PDT      | Franklin   | 300 ft tower       | well below nominal    | 16,700                       | Nevada        |                                                            |
| 3               | 5 June  | 0455 PDT      | Lassen     | 500 ft balloon     | well below nominal    | 8,600                        | Nevada        |                                                            |
| 4               | 18 June | 0455 PDT      | Wilson     | 500 ft balloon     | about half nominal    | 35,000                       | Nevada        |                                                            |
| 5               | 24 June | 0630 PDT      | Priestilla | 700 ft balloon     | above nominal         | 43,000                       | Nevada        |                                                            |
| 6               | 5 July  | 0440 PDT      | Hood       | 1,500 ft balloon   | several times nominal | 48,000                       | Nevada        | Highest yield ever fired in the continental U.S. to date.  |
| 7               | 15 July | 0430 PDT      | Diablo     | 500 ft tower       | below nominal         | 32,000                       | Nevada        |                                                            |
| 8               | 19 July | 0700 PDT      | John       | air to air missile | well below nominal    | 44,000                       | Nevada        |                                                            |
| 9               | 24 July | 0450 PDT      | Kepler     | 500 ft tower       | about half nominal    | 28,000                       | Nevada        |                                                            |
| 10              | 25 July | 0630 PDT      | Owens      | 500 ft balloon     | about half nominal    | 35,000                       | Nevada        |                                                            |
| 11              | 26 July | 0100 PDT      | Pascal A   | underground        | safety                | 5,900                        | Nevada        | Safety experiment, very low, but measurable nuclear yield. |

## U. S. NUCLEAR DETONATIONS

| No.  | Date     | Time<br>Local | Name           | Type             | Yield              | Cloud-Height<br>(ft. - feet) | Location        | Remarks                                                               |
|------|----------|---------------|----------------|------------------|--------------------|------------------------------|-----------------|-----------------------------------------------------------------------|
| 1957 |          |               |                |                  |                    |                              |                 |                                                                       |
| 12   | 7 Aug.   | 0525 PDT      | Stokes         | 1,500 ft balloon | approx. nominal    | 37,000                       | Nevada          |                                                                       |
| 13   | 18 Aug.  | 0500 PDT      | Thurston       | 500 ft tower     | below nominal      | 32,000                       | Nevada          |                                                                       |
| 14   | 23 Aug.  | 0530 PDT      | Doppler        | 1,500 ft balloon | about half nominal | 38,000                       | Nevada          |                                                                       |
| 15   | 30 Aug.  | 0540 PDT      | Franklin-Pratt | 750 ft balloon   | far below nominal  | 32,000                       | Nevada          |                                                                       |
| 16   | 31 Aug.  | 0530 PDT      | Shady          | 700 ft tower     | above nominal      | 38,000                       | Nevada          |                                                                       |
| 17   | 2 Sept.  | 0540 PDT      | Galileo        | 500 ft tower     | about half nominal | 37,000                       | Nevada          |                                                                       |
| 18   | 6 Sept.  | 0545 PDT      | Wheeler        | 500 ft balloon   | well below nominal | 17,000                       | Nevada          |                                                                       |
| 19   | 6 Sept.  | 1305 PDT      | Coulomb B      | surface          | safety             | 18,000                       | Nevada          | Safety experiment, very low but measurable nuclear yield.             |
| 20   | 8 Sept.  | 0600 PDT      | LaPlace        | 750 ft balloon   | well below nominal | 20,000                       | Nevada          |                                                                       |
| 21   | 14 Sept. | 0545 PDT      | Pineau         | 500 ft tower     | about half nominal | 40,000                       | Nevada          |                                                                       |
| 22   | 16 Sept. | 0550 PDT      | Newton         | 1,500 ft balloon | about half nominal | 32,000                       | Nevada          |                                                                       |
| 23   | 19 Sept. | 1000 PDT      | Hainier        | deep underground | 1.7 KT             | no nuclear cloud             | Nevada          | There was not any venting from the tunnel.                            |
| 24   | 23 Sept. | 0530 PDT      | Whitney        | 500 ft tower     | less than nominal  | 30,000                       | Nevada          |                                                                       |
| 25   | 26 Sept. | 0600 PDT      | Charleston 1   | 1,500 ft balloon | about half nominal | 32,000                       | Nevada          |                                                                       |
| 26   | 7 Oct.   | 0500 PDT      | Morgan         | 500 ft balloon   | well below nominal | 40,000                       | Nevada          |                                                                       |
| 1    | SAFETY   |               |                |                  |                    |                              |                 |                                                                       |
| 2    | 5 Dec.   | 1215 PST      |                | vertical shaft   | safety             |                              |                 | Some nuclear yield.                                                   |
| 3    | 9 Dec.   | 1200 PST      |                | surface          | safety             |                              |                 | Some nuclear yield.                                                   |
| 1958 |          |               |                |                  |                    |                              |                 |                                                                       |
| 1    | 28 Apr.  | 1440          | Yucca          | balloon          |                    |                              | Eniwetok        | High altitude balloon.                                                |
| 2    | 12 May   | 0530          | Fir            | barge            |                    |                              | Bikini          |                                                                       |
| 3    | 13 May   | 0630          | Koa            | surface          |                    |                              | Eniwetok        |                                                                       |
| 4    | 26 May   | 1400          | Yellowwood     | barge            |                    |                              | Eniwetok        |                                                                       |
| 5    | 11 June  | 0530          | Maple          | barge            |                    |                              | Bikini          |                                                                       |
| 6    | 15 June  | 0530          | Aspen          | barge            |                    |                              | Bikini          |                                                                       |
| 7    | 15 June  | 0630          | Walnut         | barge            |                    |                              | Eniwetok        |                                                                       |
| 8    | 26 June  | 0530          | Hedwood        | barge            |                    |                              | Bikini          |                                                                       |
| 9    | 28 June  | 0630          | Elk            | barge            |                    |                              | Eniwetok        |                                                                       |
| 10   | 29 June  | 0730          | Oak            | barge            |                    |                              | Eniwetok        |                                                                       |
| 11   | 3 July   | 0530          | Cedar          | barge            |                    |                              | Bikini          |                                                                       |
| 12   | 6 July   | 0630          | Dogwood        | barge            |                    |                              | Bikini          |                                                                       |
| 13   | 12 July  | 1530          | Poplar         | barge            |                    |                              | Bikini          |                                                                       |
| 14   | 27 July  | 0830          | Pine           | barge            |                    |                              | Eniwetok        |                                                                       |
| 15   | 31 July  | 2350          | Teak           | missile          | nagaton device     |                              | Johnston Island | Detonated in excess of 200,000 feet. Detonated at about 100,000 feet. |
| 16   | 11 Aug.  | 2330          | Orange         | missile          | nagaton device     |                              | Johnston Island |                                                                       |

## U. S. NUCLEAR DETONATIONS

| No.  | Date     | Time<br>Local | Name       | Type                 | Yield    | Cloud-Height<br>(ft. - feet) | Location | Remarks                                                                                            |
|------|----------|---------------|------------|----------------------|----------|------------------------------|----------|----------------------------------------------------------------------------------------------------|
| 1958 |          |               |            |                      |          |                              |          |                                                                                                    |
| 1    | 12 Sept. | 1300 PDT      | Otero      | 500 ft shaft         | safety   | 9,000                        | Nevada   | Some nuclear reaction.                                                                             |
| 2    | 17 Sept. | 1230 PDT      | Bernalillo | 500 ft shaft         | safety   | 7,500                        | Nevada   | Minor nuclear reaction.                                                                            |
| 3    | 19 Sept. | 0700 PDT      | Eddy       | 500 ft balloon       | 83 tons  | 11,000                       | Nevada   | Slight nuclear reaction, no organized cloud.                                                       |
| 4    | 21 Sept. | 1200 PDT      | Luna       | 500 ft shaft         | safety   |                              | Nevada   | Slight nuclear reaction.                                                                           |
| 5    | 26 Sept. | 1300 PDT      | Valencia   | 500 ft shaft         | safety   | 5,500                        | Nevada   | Slight nuclear reaction, shot vented thru tunnel, however, there was no cloud from the detonation. |
| 6    | 27 Sept. | 1700 PDT      | Mare       | tunnel               | safety   | 0                            | Nevada   |                                                                                                    |
| 7    | 29 Sept. | 0605 PST      | Mora       | 1,500 ft balloon     | 2 KT     | 19,000                       | Nevada   | Low level nuclear reaction.                                                                        |
| 8    | 5 Oct.   | 0610 PST      | Hidalgo    | 400 ft balloon       | safety   | 12,000                       | Nevada   |                                                                                                    |
| 9    | 5 Oct.   | 0815 PST      | Colfax     | 500 ft shaft         | safety   | 5,500                        | Nevada   | Slight nuclear reaction.                                                                           |
| 10   | 8 Oct.   | 1400 PST      | Tamapais   | tunnel               | 72 tons  | 0                            | Nevada   | Slight venting, no cloud.                                                                          |
| 11   | 10 Oct.  | 0630 PST      | Quay       | 100 ft tower         | 84 tons  | 10,000                       | Nevada   |                                                                                                    |
| 12   | 13 Oct.  | 0520 PST      | Lee        | 1,500 ft balloon     | 1.5 KT   | 17,000                       | Nevada   |                                                                                                    |
| 13   | 14 Oct.  | 1000 PST      | Neptune    | tunnel               | 90 tons  | 11,000                       | Nevada   | Safety experiment, shot vented.                                                                    |
| 14   | 15 Oct.  | 0800 PST      | Hamilton   | 40 ft wood tower     | 1.0 tons | 6,000                        | Nevada   |                                                                                                    |
| 15   | 15 Oct.  | 2200 PST      | Logan      | tunnel               | 5 KT     | 0                            | Nevada   | There was no venting.                                                                              |
| 16   | 16 Oct.  | 0620 PST      | Dona Ana   | 40 ft balloon        | 36 tons  | 11,000                       | Nevada   |                                                                                                    |
| 17   | 17 Oct.  | 1500 PST      | Vesta      | surface              | safety   | 10,000                       | Nevada   | Went slightly nuclear.                                                                             |
| 18   | 18 Oct.  | 0625 PST      | Rio Arriba | 12-1/2 ft wood tower | 32 tons  | 13,500                       | Nevada   |                                                                                                    |
| 19   | 22 Oct.  | 0530 PST      | Socorro    | 40 ft balloon        | 6 KT     | 26,000                       | Nevada   |                                                                                                    |
| 20   | 22 Oct.  | 0850 PST      | Wrangell   | 40 ft balloon        | 100 tons | 11,000                       | Nevada   |                                                                                                    |
| 21   | 22 Oct.  | 1540 PST      | Rushmore   | 40 ft balloon        | 180 tons | 11,500                       | Nevada   |                                                                                                    |
| 22   | 24 Oct.  | 0700 PST      | Catron     | 12-1/2 ft wood tower | safety   | 8,500                        | Nevada   | Slight nuclear reaction.                                                                           |
| 23   | 24 Oct.  | 0801 PST      | Juno       | surface              | safety   | 5,500                        | Nevada   | Slight nuclear reaction.                                                                           |
| 24   | 26 Oct.  | 0220 PST      | Sanford    | 40 ft balloon        | 4.5 KT   | 26,000                       | Nevada   |                                                                                                    |
| 25   | 26 Oct.  | 0800 PST      | deBaca     | 1,500 ft balloon     | 2.5 KT   | 17,500                       | Nevada   |                                                                                                    |
| 26   | 27 Oct.  | 0630 PST      | Charles    | 52-1/2 ft tower      | safety   | 6,000                        | Nevada   | Slight nuclear reaction.                                                                           |
| 27   | 28 Oct.  | 1600 PST      | Evans      | tunnel               | 55 tons  | 0                            | Nevada   | There was venting.                                                                                 |
| 28   | 29 Oct.  | 0320 PST      | McKean     | 50 ft steel tower    | 0        | 6,000                        | Nevada   |                                                                                                    |
| 29   | 29 Oct.  | 0645 PST      | Bamford    | 25 ft wood tower     | 6 tons   | 7,500                        | Nevada   |                                                                                                    |

## U. S. NUCLEAR DETONATIONS

| No.   | Date    | Time<br>Local | Name     | Type             | Yield        | Cloud-Height<br>(MFL - feet) | Location    | Remarks                         |
|-------|---------|---------------|----------|------------------|--------------|------------------------------|-------------|---------------------------------|
| 1250  |         |               |          |                  |              |                              |             |                                 |
| 30    | 29 Oct. | 1900 PST      | Santa Fe | 1,500 ft balloon | 1.25 KT      | 18,000                       | Nevada      |                                 |
| 31    | 30 Oct. | 0700 PST      | Blanca   | tunnel           | 19 KT        | low                          | Nevada      | Slight venting, very low cloud. |
| APRUS |         |               |          |                  |              |                              |             |                                 |
| 1     | 27 Aug. |               |          | high altitude    | (Total yield |                              | S. Atlantic | (Detonated at an                |
| 2     | 30 Aug. |               |          | high altitude    | ) of 3 to    |                              | S. Atlantic | altitude of                     |
| 3     | 6 Sept. |               |          | high altitude    | (6 KT.       |                              | S. Atlantic | (about 300 miles.               |

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## U. S. NUCLEAR DETONATIONS

| No.            | Date     | Time<br>Local | Type     | Yield         | Location                 | Remarks                    |
|----------------|----------|---------------|----------|---------------|--------------------------|----------------------------|
| 1952 HURRICANE |          |               |          |               |                          |                            |
| 1              | 3 Oct.   |               | ship     | kiloton range | White Hall Islands       |                            |
| 1953 TOTEM     |          |               |          |               |                          |                            |
| 1              | 15 Oct.  | 0700          | tower    | kiloton range | Woomera                  | (Test held at Rhu Field,   |
| 2              | 27 Oct.  | 0700          | tower    | kiloton range | Woomera                  | ) 300 miles NW of Woomera. |
| 1956 MESAIC    |          |               |          |               |                          |                            |
| 1              | 16 May   |               | tower    | kiloton range | White Hall Islands       |                            |
| 2              | 19 June  |               | tower    | kiloton range | White Hall Islands       |                            |
| BUFFALO        |          |               |          |               |                          |                            |
| 1              | 27 Sept. |               | tower    | kiloton range | Maralinga Proving Ground |                            |
| 2              | 4 Oct.   |               | surface  | low yield     | Maralinga Proving Ground |                            |
| 3              | 11 Oct.  |               | air drop | low yield     | Maralinga Proving Ground | First air drop.            |
| 4              | 22 Oct.  |               | tower    | kiloton range | Maralinga Proving Ground |                            |
| 1957 GRAPPLE   |          |               |          |               |                          |                            |
| 1              | 15 May   |               | air drop | megaton range | Christmas Island area    |                            |
| 2              | 31 May   |               | air drop | megaton range | Christmas Island area    |                            |
| 3              | 19 June  |               | air drop | megaton range | Christmas Island area    |                            |
| AWFLER         |          |               |          |               |                          |                            |
| 1              | 14 Sept. | 1500          | tower    | low yield     | Maralinga Proving Ground |                            |
| 2              | 25 Sept. | 1000          | tower    | kiloton range | Maralinga Proving Ground |                            |
| 3              | 9 Oct.   | 1700          | balloon  | kiloton range | Maralinga Proving Ground |                            |
| GRAPPLE        |          |               |          |               |                          |                            |
| 1              | 8 Nov.   |               | air drop | megaton range | Christmas Island area    |                            |
| 1958 GRAPPLE   |          |               |          |               |                          |                            |
| 1              | 28 April |               | air drop | megaton range | Christmas Island area    |                            |
| 2              | 22 Aug.  |               | balloon  | kiloton range | Christmas Island area    |                            |
| 3              | 2 Sept.  |               | air drop | megaton range | Christmas Island area    |                            |
| 4              | 11 Sept. |               | air drop | megaton range | Christmas Island area    |                            |
| 5              | 23 Sept. |               | balloon  | kiloton range | Christmas Island area    |                            |

## U.S.S.R. NUCLEAR DEVIATIONS

| No.       | Date                  | Type     | Yield                 | Location | Remarks                                                                                                          |
|-----------|-----------------------|----------|-----------------------|----------|------------------------------------------------------------------------------------------------------------------|
| 1949<br>1 | 29 Aug.               |          |                       | USSR     | First Russian nuclear detonation.                                                                                |
| 1951<br>1 | 3 Oct. <sup>a</sup>   |          |                       | USSR     | Statement by Press Secretary Shorn, detonated recently.                                                          |
| 2         | 22 Oct. <sup>a</sup>  |          |                       | USSR     | Statement by White House.                                                                                        |
| 1953<br>1 | 12 Aug.               |          | thermonuclear fission | USSR     | Part of a series                                                                                                 |
| 2         | 23 Aug.               |          |                       | USSR     | Part of a series, energy release equivalent to type detonated at Nevada Test Site.                               |
| 1954<br>1 | 26 Oct. <sup>a</sup>  |          |                       | USSR     | Part of a series, statement by Mr. Strauss, series began in mid-Sept. and continued at intervals to the present. |
| 1955<br>1 | 4 Aug. <sup>a</sup>   |          |                       | USSR     | Part of a series, statement by Dr. Libby-detested in the past few days.                                          |
| 2         | 24 Sept. <sup>a</sup> |          |                       | USSR     | Part of a series, statement by Mr. Strauss - detonated recently.                                                 |
| 3         | 10 Nov. <sup>a</sup>  |          |                       | USSR     | Part of a series, statement by Mr. Strauss - detonated recently.                                                 |
| 4         | 23 Nov. <sup>a</sup>  | air drop | megaton range         | USSR     | Part of a series, statement by Mr. Strauss                                                                       |
| 1956<br>1 | 21 Mar. <sup>a</sup>  |          |                       | USSR     | Part of a series, statement by Mr. Strauss detonated in the past few days.                                       |
| 2         | 2 Apr. <sup>a</sup>   |          |                       | USSR     | Part of a series, statement by Mr. Strauss detonated recently.                                                   |
| 1         | 24 Aug.               |          | less than a megaton   | Siberia  | Part of a series                                                                                                 |
| 2         | 30 Aug.               |          | large test            | Siberia  | Part of a series                                                                                                 |
| 3         | 2 Sept.               |          |                       | USSR     | Part of a series                                                                                                 |
| 4         | 10 Sept.              |          |                       | USSR     | Part of a series, announced by Soviet Union                                                                      |
| 5         | 17 Nov.               |          | large test            | USSR     | Part of a series                                                                                                 |
| 1957<br>1 | 19 Jan.               |          |                       | USSR     | Part of a series                                                                                                 |
| 2         | 8 Mar.                |          |                       | USSR     | Part of a series                                                                                                 |
| 3         | 3 April               |          |                       | USSR     | Part of a series                                                                                                 |
| 4         | 6 April               |          |                       | USSR     | Part of a series                                                                                                 |
| 5         | 10 April              |          | large                 | USSR     | Part of a series                                                                                                 |
| 6         | 12 April              |          |                       | USSR     | Part of a series                                                                                                 |
| 7         | 16 April              |          | large                 | Siberia  | Part of a series-largest tested so far for this series.                                                          |

## U.S.S.R. NUCLEAR DEVIATIONS

| No.       | Date                 | Type | Yield                        | Location | Remarks                                                                              |
|-----------|----------------------|------|------------------------------|----------|--------------------------------------------------------------------------------------|
| 1957<br>1 | 22 Aug.              |      | substantial aim              | Siberia  |                                                                                      |
| 2         | 9 Sept. <sup>a</sup> |      | moderate intensity           | Siberia  | Statement by Mr. Strauss, detonated within the past two days.                        |
| 3         | 24 Sept.             |      | megaton range                | Arctic   |                                                                                      |
| 4         | 6 Oct.               |      | hydrogen device              | USSR     | Announced by Soviet Union as a hydrogen device, ABC said it was of substantial size. |
| 5         | 10 Oct.              |      | small explosion              | Arctic   |                                                                                      |
| 6         | 20 Oct.              |      |                              | Siberia  |                                                                                      |
| 1958<br>1 | 23 Feb.              |      | megaton range                | Arctic   |                                                                                      |
| 2         | 27 Feb.              |      | megaton range                | Arctic   |                                                                                      |
| 3         | 27 Feb.              |      | large                        | Arctic   |                                                                                      |
| 4         | 14 Mar.              |      | not in megaton range         | Arctic   |                                                                                      |
| 5         | 14 Mar.              |      | not in megaton range         | Siberia  |                                                                                      |
| 6         | 15 Mar.              |      | below megaton range          | Siberia  |                                                                                      |
| 7         | 20 Mar.              |      | small range                  | Siberia  |                                                                                      |
| 8         | 21 Mar.              |      |                              | Siberia  |                                                                                      |
| 9         | 22 Mar.              |      | medium range                 | Arctic   |                                                                                      |
| 10        | 30 Sept.             |      | moderate to high             | Arctic   |                                                                                      |
| 11        | 30 Sept.             |      | moderate to high             | Arctic   |                                                                                      |
| 12        | 2 Oct.               |      | moderate                     | Arctic   |                                                                                      |
| 13        | 2 Oct.               |      | moderate                     | Arctic   |                                                                                      |
| 14        | 5 Oct.               |      |                              | Arctic   |                                                                                      |
| 15        | 10 Oct.              |      | relatively high <sup>a</sup> | Arctic   |                                                                                      |
| 16        | 12 Oct.              |      | large <sup>a</sup>           | Arctic   |                                                                                      |
| 17        | 15 Oct.              |      | large <sup>a</sup>           | Arctic   |                                                                                      |
| 18        | 16 Oct.              |      | large <sup>a</sup>           | Arctic   |                                                                                      |
| 19        | 19 Oct.              |      | small <sup>a</sup>           | Arctic   |                                                                                      |
| 20        | 20 Oct.              |      | large <sup>a</sup>           | Arctic   |                                                                                      |
| 21        | 22 Oct.              |      | large <sup>a</sup>           | Arctic   |                                                                                      |
| 22        | 24 Oct.              |      | large <sup>a</sup>           | Arctic   |                                                                                      |
| 23        | 25 Oct.              |      | relatively large             | Arctic   |                                                                                      |
| 24        | 1 Nov.               |      | relatively low               | Siberia  |                                                                                      |
| 25        | 3 Nov.               |      | relatively low               | Siberia  |                                                                                      |

This detonation was in a larger range than the test this day before.

Lesser yield than the detonations (4) which occurred on 30 Sept. and 2 Oct.

<sup>a</sup>Time of announcement, not necessarily test data.

<sup>a</sup>Mr. Strauss on Oct. 24, 1958, announced that seven of these test detonations have been of high yield, meaning, that each had an explosive power equal to millions of tons of TNT.

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STATEMENT OF THE NATIONAL ACADEMY OF SCIENCES COMMITTEE ON THE METEOROLOGICAL ASPECTS OF THE EFFECTS OF ATOMIC RADIATION

The following statement was unanimously agreed upon by the National Academy of Sciences Committee on the Meteorological Aspects of the Effects of Atomic Radiation:

The bulk of the long-lived radioactive debris which has contributed to global fallout comes from high yield explosions which have injected radioactive material into the stratosphere. The evidence available today indicates that this stratospheric debris is neither uniformly distributed in the stratosphere nor uniformly deposited on the ground. Based on data collected mostly over land areas, global fallout remote from test sites has been observed to be larger in the Northern Hemisphere than the Southern Hemisphere and larger in the middle latitude of the Northern Hemisphere than in the tropical or polar regions and to have been less in arid regions. Although part of the peak in the middle latitude of the Northern Hemisphere is due to the locations of the test sites, there is evidence that the fine  $\text{Sr}^{90}$  particles injected into the tropical stratosphere within a factor of two or less.

Radioactive material injected into the stratosphere at temperate and polar latitudes return to the earth at middle latitudes of the same hemisphere with greater speed and with higher concentration than is the case with the same amount of material injected into the tropical stratosphere. There is a seasonal effect in the deposition from the stratosphere with a maximum in the spring season.

Various methods exist for estimating the stratospheric inventory of radioactive debris. These estimates, derived from independent approaches, are in agreement within a factor of two or less.

## APPENDIX J

## CLASSIFICATION AND DECLASSIFICATION

CONGRESS OF THE UNITED STATES,  
JOINT COMMITTEE ON ATOMIC ENERGY,  
Washington, D.C., April 8, 1959.

Mr. A. R. LUEDECKE,  
General Manager, U.S. Atomic Energy Commission,  
Washington, D.C.

DEAR MR. LUEDECKE: In connection with the Special Subcommittee on Radiation's hearings to be held beginning May 5, Mr. Hollfield has requested that the Commission, as soon as practicable, provide us with information on the classification status of reports which the 1957 hearings indicated were classified.

Thus, beginning on page 29 of the committee print there is a list of weapons tests reports (AEC restricted data) which have been furnished to the FCDA. Many of these reports seem to bear titles indicative that they may be biological and medical reports rather than straight weapons reports. It would be appreciated if you would provide us with information as to what is the current status of the classification of these reports.

It is my understanding that Mr. Hollfield raised the question of the classification of these reports in a FCDA hearing a couple of years ago and that Dr. Dunham indicated that the reports were under review. Specifically, would you indicate how many of the following reports have been declassified:

WT 8, 9, 12, 15, 16, 22, 27, 43, 68, 70, 89, 311, 312, 315, 316, 356, 362, 372, 407, 425, 509, 527, 531, 543, 544, 558, 614, 616, 615, 731, 737, 744, 746, 775, 778, 790, 793, 794, 811, and ITR-913, 916, and 915.

It would also be appreciated if you would review similar reports for the period 1954 to the present to ascertain whether all data on the biological and medical aspects of fallout and weapons effects have been declassified.

Sincerely yours,

JAMES T. RAMEY, Executive Director.

U.S. ATOMIC ENERGY COMMISSION,  
Washington, D.C., May 1, 1959.

Mr. JAMES T. RAMEY,  
Executive Director,  
Joint Committee on Atomic Energy,  
Congress of the United States.

DEAR MR. RAMEY: I refer to your letter dated April 8, 1959, in which you inquired about the present classification status of a number of weapons tests reports.

The following reports have been declassified:

WT 8, 12, 15, 16, 22, 70, 311, 312, 315, 316, 356, 362, 372, 407, 425, 509, 527, 531, 543, 544, 615, 616, 737, 746, 775, 778, 790, 793, 794 and 811.

Reports WT 8, 9, 27, 43, 63, 89, 558, 614, 731, 744, 913, and ITR 915 and 916 cannot be declassified as written under the current rules used jointly by the Atomic Energy Commission and the Department of Defense. However, these reports are now being concurrently reviewed for possible declassification with deletions. We shall advise you of the classification status of these reports after the necessary reviews are completed.

Sincerely yours,

A. R. LUEDECKE, General Manager.

From the office of the Joint Committee on Atomic Energy.

No. 210

March 19, 1959

For immediate release

Senator Clinton P. Anderson, Democrat of New Mexico, chairman of the Joint Committee on Atomic Energy, made the following statement answering inquiries

as to the public release by the Department of Defense of classified information concerning high altitude nuclear weapons tests in the South Atlantic last September:

"I am not pleased by the way the ARGUS story (the high altitude shots in the South Atlantic) was turned loose. The Joint Committee was briefed about this last January and many members raised the question as to why it could not be released then. The Department of Defense gave us reasons for keeping it classified 'Secret' and we accepted its reasoning.

"Now it is out in the open and I therefore feel free to release a letter Mr. Durham and I have today sent to General Loper. Obviously, there were lengthy preparation for releasing this story. But the Joint Committee on Atomic Energy, which protected the secret label, did not hear officially that it was released until after 10 o'clock this morning. That strikes me as a poor example of cooperation. Our letter speaks for itself.

"It is curious that at the same time the Department of Defense was leaking this secret information, it was gagging the Joint Committee on an unclassified but most important bit of information on fallout. I believe the public interest requires that a certain Defense letter to the Joint Committee on Atomic Energy on fallout be made public at once."

[Attachment]

CONGRESS OF THE UNITED STATES,  
JOINT COMMITTEE ON ATOMIC ENERGY,  
March 19, 1959.

HON. HERBERT B. LOPER,  
Assistant to the Secretary of Defense for Atomic Energy, Department of Defense, the Pentagon, Washington, D.C.

DEAR GENERAL LOPER: On the morning of March 19, 1959, headlines in the Washington Post newspaper announced that the "U.S. Reveals High Altitude A-Tests; Possibility of Anti-Missile Shield Seen." An accompanying front-page story with dateline March 18, New York, discussed the high altitude nuclear tests conducted last September by the United States and identified Dr. Frank H. Shelton, Technical Director of the Armed Forces Special Weapons Project, as the person releasing the information.

On January 13 and 19, 1959, you were present in an executive session meeting of the Joint Committee on Atomic Energy at which Dr. Shelton and other representatives of the Armed Forces special weapons project discussed these tests, the existence of which were considered classified information. During your testimony on January 19, you mentioned that consideration was being given to a public release of the fact that the tests were conducted and their purpose. You informed the committee that if a decision was made to release the information, you would "certainly advise the committee to that effect." Despite your assurance, the Joint Committee was not informed prior to the release.

I would appreciate it if you would advise me concerning the circumstances leading to the release of this previously secret information, when it was declassified and by whom, and the reasons for the manner in which it was released. I would also desire to know why the Joint Committee was not notified in advance of the release.

Sincerely yours,

CLINTON P. ANDERSON,  
Chairman.  
CARL T. DURHAM,  
Vice Chairman.

No. 211

For release to a.m.'s of March 22, 1959

From the office of the Joint Committee on Atomic Energy.

Recent classified correspondence by the Defense Department and the Atomic Energy Commission revealing new fallout data was made public today in unclassified form by Senator Clinton P. Anderson, chairman of the Joint Congressional Committee on Atomic Energy, together with the following statement:

"In commenting the other day on the Defense Department leak of classified information on the ARGUS shots (high altitude shots in the South Atlantic in September 1958) I pointed out that it was curious that the Defense Department

at the same time was gagging the Joint Committee on making public some important data on fallout from weapons tests.

"The Defense Department and the AEC have now released their fallout correspondence with classified deletions, and it is made public in the attachments. First is a letter to me, dated February 19, 1959, by the Defense Department, revealing new data from classified sources on the residence time of fallout in the stratosphere, and the areas of maximum drip-out. Next is a letter from the AEC spokesman, Dr. W. F. Libby, commenting on the Defense Department letter and research project on which it was based. Then there is a transmittal letter from AEC stating their official reservations. Finally, there is a brief chronology of our attempts to make this information public.

"The process of making public the ARGUS and fallout information is an example of how difficult it is to make available to the public the information it is entitled to have.

"The February 19 Defense Department letter states that their measurements indicate that the radioactivity in the stratosphere has a residence of half life of 2 years instead of 7 years as had previously been assumed by AEC. It also indicates that there is a latitude band of maximum drip-out of the fallout from the stratosphere which occurs from 35° to 50° north or south. This area includes the northern part of the United States, and the letter states that 'the concentration of strontium 90 on the surface of the earth is greater in the United States than in any other area in the world.'

"In layman's language," Senator Anderson stated, "it looks like strontium 90 isn't staying up in there as long as AEC told us it would, and the fallout is greatest on the United States. Perhaps this information may account, in part, for the recent higher readings of radioactivity in soils and plants.

"This new data appears to further contradict the official doctrine of AEC spokesmen as to residence time of fallout in the stratosphere and the theory that stratospheric fallout tends to drip out uniformly throughout the earth. The AEC letter of February 27, 1959, ought to be checked for consistency with the speech of the same AEC spokesman on March 13, 1959, at Seattle.

"The Joint Committee will look into these matters when it holds its fallout hearings in May of this year under the chairmanship of Congressman Chet Holifield of the Special Subcommittee on Radiation."

[Attachment No. 1]

OFFICE OF THE SECRETARY OF DEFENSE,  
Washington, D.C., February 19, 1959.

HON. CLINTON P. ANDERSON,  
Chairman, Joint Committee on Atomic Energy.

DEAR MR. CHAIRMAN: The following is a brief status report outlining the present programs for analyzing and evaluating the radiation hazards resulting from atomic detonations.

Fallout reports from Operation Redwing (1956), Plumbbob (1957), and Hardtack (1958) are currently under preparation.

The hazards of local contamination from nuclear weapon detonations have been fairly well delineated. However, the difficulty in accurately predicting the rapidly varying atmospheric condition results in uncertainties as to the area of fallout. Predictions of local fallout contours from enemy bombs must be based on a large number of assumptions such as the type of weapon, height of burst, and yield. These unknowns do not allow accurate prediction of fallout from enemy bursts during wartime. Delineation of contaminated areas by airborne radiac instruments after deposition of the fallout is presently practicable and will be of considerable military and civil value during wartime.

The deposition of worldwide fallout or worldwide surface contamination is now beginning to be accurately measured. [Classified portion deleted.] Recent indications are that the radioactivity in the stratosphere has a residence half life of 2 years (in contrast to the previously assumed value of about 7 years) and the present amount of Sr<sup>90</sup> in the stratosphere would be maintained by the injection of about 8 megatons of fission products per year. The concentration of the Sr<sup>90</sup> on the surface of the earth is greater in the United States than in any other area of the world. The danger of carbon-14 and cesium-137 has been examined and the immediate probability of any one individual being affected is about 1 in 500,000.

The risk of damage resulting from the testing of weapons is therefore extremely small and much less than other common-day occurrences such as X-rays, automobiles, chemical contaminants, household cleaners, etc. However, the probable casualties attributable to radioisotopes from weapons testing, when summed over the populations of thousands of years, create a moral issue that could be of considerable propaganda importance.

The distribution of the radioactive debris in the stratosphere as a result of detonations to date is not clearly defined as to its altitude and latitude variation. The altitude dependence partially determines the drip-out rate and the latitude dependence influences the extent to which the worldwide fallout is uniform over the earth. Tentative conclusions to date indicate that three-tenths of the quantity of radioactive debris leaves the stratosphere each year, that the north-south diffusion of radioactive particles in the stratosphere does exist, and that in both hemispheres, there is a latitude band of maximum drip out which is from 35° to 50° north or south.

There is a need for more experimental and collecting programs in the following areas of the effects and behavior of fallout from nuclear weapons:

- (a) Amount of fallout deposited locally from a low height of burst.
- (b) More accurate determination of the drip-out rate of radioactive particles from the stratosphere.
- (c) Further define the estimate of the amount of radioactivity formed per KT of fission yield.
- (d) The refinement of measuring techniques to account for all radioactivity produced from a nuclear yield.
- (e) Advancements in the knowledge of fireball chemistry, physics, and particle behavior.
- (f) Response of biological systems to radiation.

Sincerely yours,

HERBERT B. LOPER,

*Assistant to the Secretary of Defense (Atomic Energy).*

[Attachment No. 2]

FEBRUARY 27, 1959.

HON. HERBERT B. LOPER,  
*Chairman, Military Liaison Committee.*

DEAR GENERAL LOPER: In connection with your letter to Senator Anderson of February 19, 1959, concerning radiation hazards resulting from atomic detonations, I have just completed a study of data which you kindly made available to us last December. I am sorry that, because of the complexity of the problem and my preoccupation with other duties, I have been so slow in finishing my consideration of the data and in sending on my comments.

I think your letter to Senator Anderson is an excellent exposition of the present position we are in. There are, however, one or two points you make on which I believe further words are necessary in order to resolve some questions.

The extensive data that have already been published by Project Sunshine and the United Kingdom study group, together with your beautiful work, still leave us, despite their great volume and complexity, in some uncertainty, as you say, as to the distribution of the radioactive debris in the stratosphere to both altitude and latitude variation. Since the altitude variation determines in part the drip-out rate and thus the residence half life in the stratosphere, this quantity is left in some doubt. My own present conclusion is in agreement with yours as stated in your letter, in that my previous value of 7 years for this important number is too long and that it should be reduced. In a restudy of this question, being released March 13 in Seattle, a copy of which will be sent you as soon as it is printed, a new value of about 4 years rather than the earlier 7 is arrived at. I find it difficult to push it down to the 2 years you give as an indicative value.

On the amount of strontium 90 in the stratosphere, at the present time there is a somewhat larger difference in our estimates which may be due to your not having included the Russian series of last October which in itself alone, according to my estimates, increased the stratospheric inventory by about 50 percent. You give the present inventory as requiring 6 MT (megatons fission equivalent) per year to be maintained at its present level. For a half life of 2 years this corresponds to only 17 MT total and appears to leave too little room for the injections from tests before last October, which I estimate still have left

some 25 to 30 MT in the stratosphere for a total at present of about 42 MT and a corresponding required rate of injection for steady maintenance of about 7 MT per year. The closeness of this figure to your 6 MT per year number shows how badly we need further information on the actual stratospheric content.

You indicate that the stratospheric fallout occurs at maximum rates in the 30° to 50° bands of latitude in both hemispheres. This old argument still is not quite settled, I believe, although the evidence in favor of your conclusion is increasing. My principal difficulties with it at the moment are that we know that a considerable part of the peak in observed fallout in these latitudes in the Northern Hemisphere is due to tropospheric or local fallout which was never in the stratosphere and the evidence for a corresponding peak in the Southern Hemisphere seems to be rather weak.

With respect to the carbon 14 and cesium 137 hazards, the laboratories measuring radioactive rates in various parts of this country, in Europe and New Zealand have sent me data on the present increase in the carbon 14 content of living matter which amounts to about 10 percent of the natural level of carbon 14 from the cosmic rays which in itself corresponds to about 1.5 milliroentgen per year—about 1.5 percent of the average total natural dose rate. Turning to cesium 137, Dr. E. C. Anderson in the Health Division at our Los Alamos Laboratory has just reported data on the human level in the United States and Europe for the late summer and early fall of last year which amount to an average of about 75 micromicrocuries per gram of body potassium for an internal dose rate of about 3 milliroentgens per year. The total cesium 137 fallout in the United States now amounts to about 50 millicuries per square mile. This adds about 1 mr/yr of external dose for a total of about 4 mr/yr due to cesium 137 which is about 3 percent of the natural average radiation dose rate from natural radioactivity and the cosmic rays. I can't tell whether these numbers are in strict keeping with your estimate that the immediate probability of any one individual being affected by bomb test carbon 14 and cesium 137 is about 1 in 500,000 but I think your estimate looks reasonable.

On the many other points in your letter I find myself in complete agreement, particularly about the importance of more experimental and collecting programs on the amount of fallout deposited locally from a low height of burst. Since it may be that we will not again have the opportunity to test devices, at least above ground, it is particularly important to consider whether we may not collect more information on this point from past tests. I believe there are some possibilities of doing this and I suggest that we undertake such a program jointly right away.

Sincerely yours,

W. F. LIBBY, *Commissioner.*

Distribution:

1. Hon. Clinton P. Anderson.
2. Rear Adm. Edward N. Parker.
3. Dr. Frank Shelton.
4. Dr. Lester Machta.
5. Mr. John A. McCone.
6. Mr. Harold S. Vance.
7. Mr. John F. Floborg.
8. Mr. John S. Graham.
9. Gen. A. R. Luadecke.
10. Gen. A. D. Starbird.
11. Dr. Charles Dunham.

[Attachment No. 3]

COPY OF LETTER TO THE JOINT COMMITTEE, RECEIVED MARCH 21, 1959, FROM THE AEC

This is in reply to your letter of March 9, 1959, by which you forwarded a copy of General Loper's letter to Senator Anderson dated February 19, 1959, and requested our comments thereon.

Commissioner W. F. Libby has written his comments to General Loper in a letter dated February 27, a copy of which was sent to Senator Anderson at that time. For your convenience another copy of Dr. Libby's letter is attached.

The revised estimates of stratospheric burden and the residence time presented by General Loper are consistent both with the data referred to by General

Loper and with the "Ashcan" data obtained by the Atomic Energy Commission in its balloon sampling up to 90,000 feet. However, it should be kept in mind that knowledge of the stratospheric content alone is not sufficient to determine retention time. In addition one needs the knowledge of either the stratospheric injection or of total stratospheric fallout as a function of time. Within the range of accuracy with which fallout has been measured, observed fallout to date is not incompatible with General Loper's estimate of the injection rate which would be required to maintain the present stratospheric burden.

The two main reasons for the uncertainty in the stratospheric burden and residence time are (1) that the entire stratosphere has not been adequately surveyed from pole to pole and up to altitudes beyond which the overlying radioactive debris can be confidently neglected and (2) that the data obtained at the higher altitudes by balloon only are subject to sizable sampling errors, uncertainties of collection efficiency of the sampling filters, and radiochemical analysis errors due to the small amounts collected.

As a consequence of these uncertainties we do not consider that the data now available are sufficiently decisive to resolve the differences between the estimates of stratospheric content and retention time made by General Loper and the higher estimates given by Dr. Libby in his letter to General Loper. It may be observed that on the basis of the estimates made by General Loper the total worldwide fallout of long-lived radioactive fission products anticipated from all tests up to date would be roughly two times the total deposition so far and that on the basis of Dr. Libby's estimate the total would be roughly three times.

We concur with General Loper in recognizing the need for further investigations along the lines suggested in his letter. We plan to continue our efforts in all these fields. In particular, we hope to be able to differentiate Operation Hardtack surface-burst debris and high-altitude debris, by analysis of tungsten and rhodium isotopes, respectively, and, in turn, to distinguish these from the recent U.S.S.R. debris. In this way it should be possible to obtain a much better picture of the actual patterns and rates of spread of stratospheric debris originating in different latitudes and altitudes.

The information bracketed in red on the first page of the attached copy of Dr. Libby's letter of February 27, 1959, is considered by the originating agencies to be confidential defense information. With these deletions Dr. Libby's letter is declassified.

Sincerely yours,

A. R. LUEDECKE, *General Manager.*

[Attachment No. 4]

BRIEF CHRONOLOGY OF ACTION BY JOINT COMMITTEE ON ATOMIC ENERGY TO MAKE PUBLIC DEFENSE DEPARTMENT REPORT ON FALLOUT

December 1958: Dr. Libby furnished new data by Defense Department indicating that the radioactivity in the stratosphere has a residence half life of 2 years instead of previously assumed value of 7 years.

February 20, 1959: Joint Committee received fallout report by the Department of Defense dated February 19, 1959, classified "confidential--restricted data."

February 27, 1959: Confidential letter sent to Defense Department by Dr. Libby with copy to Joint Committee chairman in which Dr. Libby arrived at new value of 4 years instead of previous 7 years.

March 9, 1959: Joint Committee by letter this date to the Defense Department questioned the reasons for the confidential classification of the report and inquired as to what extent the information could be discussed in public without compromising classified information.

A separate letter this date was also sent to the AEC requesting the Commission's views on the report and to what extent the conclusions affected previous assumptions and statements.

March 13, 1959: Restudy by AEC of worldwide stratospheric fallout released by Seattle, Wash., in which no mention of Defense Department study is made and which maintains position of a residence time of 5 to 10 years, selecting 6 years as the mean residence time of stratospheric fallout. Results of another AEC analysis Project Ash Can which indicated a residence time of 3 years was discounted as being doubtful. No mention was made that the Department

of Defense conclusions of residence half life of 2 years tended to support results of Project Ash Can.

March 18, 1959: By letter, the Defense Department advised the Joint Committee that only one sentence in the report contained classified information and after identifying it went on to state: "Although the remainder of the letter is unclassified, the Department recommends that it not be discussed in public because there is not full agreement as to the interpretation of the data that has been obtained so far. We believe it would be far better before the data and conclusions are made public that there be a close agreement amongst the investigators concerned. Therefore, we believe that until the results are more than preliminary, the confidential classification should remain on the letter."

March 20, 1959: Letter received by Joint Committee from the Defense Department advising the report could be made public with deletion of the one classified sentence.

March 21, 1959: Letter received from AEC stating what portion of Dr. Libby's confidential letter of February 27, 1959, to the Department of Defense does not contain classified information.

Letter and report released by Joint Committee after deletion of classified information.

## APPENDIX K

## FALLOUT RESEARCH AND ORGANIZATION

STATEMENT BY JOHN A. MCCONE, CHAIRMAN, ATOMIC ENERGY COMMISSION,  
BEFORE JOINT COMMITTEE ON ATOMIC ENERGY MARCH 24, 1959

As I have said to this committee and publicly on a number of occasions, radioactive fallout is a matter of greatest importance to me and to my fellow Commissioners. We do not take this question lightly; we have not dismissed it as unimportant to the people of this country and, indeed, the world.

I wish to make three points:

1. In this fiscal year, the Atomic Energy Commission will spend \$18 million in research on problems associated with radiation standards and protection. In addition, \$2.5 million for sampling and analysis for national and worldwide fallout studies, plus \$450,000 for fellowships for training in health physics, industrial hygiene, and so forth. In fiscal year 1960 the figures for radiation standards and protection increase to \$20 million, and these funds are provided out of a \$50 million budget for biomedical research. Since 1946 when AEC was established we have spent approximately \$125 million on the biomedical radiation research.

The equivalent of 800 scientists are engaged in this work, backed by 800 to 1,000 laboratory technicians. Work is carried on at Brookhaven, Argonne, Oak Ridge, University of California, Radiation Laboratory at Berkeley, and through contract with 204 universities and 19 industrial corporations.

Arrangements for sampling and other fallout information exist between the AEC and the Weather Bureau, Department of Agriculture, Public Health Service, and the Food and Drug Administration.

Active sampling programs are being conducted in a number of other countries with whom we exchange information. These countries are widely dispersed over the world and include, for example, Japan, New Zealand, Norway, England, and Brazil.

A gummed paper sampling program is being conducted at 100 stations in 37 different countries. We have also 64 soil sampling stations in foreign countries and 17 in the United States from soil samples which are regularly collected.

In the performance of our work we have sampled air at altitudes up to 90,000 feet at four locations throughout the world. This is done by sending devices up in balloons or planes equipped to sample air up to high altitudes and then recovering the devices and analyzing the results. This work has been going on for 3 years. In addition, we have various means for sampling the fallout by recovering the debris which comes out of the atmosphere and analyzing it, and none of this work is classified.

No Atomic Energy Commission information relating to the radioactive content of the atmosphere and the amount of fallout has been withheld from the public or from the United Nations. We have given out the estimated and assumed theoretical fission product distribution worldwide from all tests conducted by the United States, U.S.S.R., and United Kingdom.

All significant information known to the AEC from its extensive and elaborate research program was made available to the United Nations Radiation Committee. In fact, the AEC was the principal source of information for that committee, and this committee was founded by motion of the U.S. delegate to the U.N., which was initiated at the instance of the AEC and the Department of State.

The importance of the fallout and sampling program is thoroughly recognized by the AEC and it is our intent to continue an active program. However, we have no desire to preempt this area of activity and if the Congress and the executive department wish to assign part of this activity to other Federal agencies we will cooperate with them to the fullest.

However, we do not wish to see this activity diminished or unattended and I am sure this committee and the Congress feel likewise. Otherwise, you would

not have appropriated \$17 million in fiscal year 1959 and given consideration to our \$20 million request for fiscal year 1960.

The AEC is the only agency in Government that has engaged in extensive research work in the sampling of the atmosphere and conducting fallout studies on a worldwide basis. In the past year the Department of Defense conducted a series of experiments which were considered by DOD as highly classified. These results produced data on the atmospheric content of radioactive substance supplementing that developed by the AEC. These differences were set forth in letters which have been made public. I hope the differences will be resolved.

I hope the Department of Defense will place their findings in the public domain. Dr. Libby, spokesman for the AEC in this matter and General Loper, spokesman for the Department of Defense, have assured me that there has been no attempt at any time to suppress or modify the DOD report in the interest of reconciling these differences or scientific judgment.

Finally, I wish to advise this committee that I have taken the following actions:

1. We enthusiastically support the plan of this committee to hold a series of hearings on this very important subject and our staffs have been working with the Joint Committee staff on this program. I urge if possible that these hearings be held the last week in April and the first week in May as during these days a principal part of the scientific fraternity will be assembled in Washington and many very important witnesses will be available to this committee.

2. I have requested that a review of this matter be made at once on a governmentwide basis and that all interested Government agencies participate. We are urging that this important conference be arranged by the National Academy of Sciences and that a meeting be held the latter part of May.

3. Because of my comparative newness in my job, I have asked Dr. Warren Johnson, Chairman of our General Advisory Committee to call a special meeting of his Committee in Washington on April 10 and 11 for the purpose of reviewing this question and of advising me of any additional steps the Commission might take to further protect the public interest. In ordering this meeting I have requested that Dr. Johnson confer with Dr. Shields Warren, U.S. Representative on U.N. Radiation Committee, members of the AEC Advisory Committee on Biology and Medicine, Dr. Dunham and other representatives of our Division of Biology and Medicine, and other specialists in this field. The advice of the General Advisory Committee when received will be transmitted to this committee and will be made public.

I would like to point out to you that this question of the basic standards of radiation protection have been developed by the National Committee on Radiation Protection and Measurements which is sponsored by U.S. National Bureau of Standards. On this Committee are representatives of both public and private organizations, including the Department of Health, U.S. Atomic Energy Commission, International Association of Government Labor Officials, the American Medical Association, the American Dental Association, the National Bureau of Standards, the American College of Radiology, U.S. Navy, the Army, the Air Force, the Atomic Industrial Forum, and others. The recommendations of this Committee are not only accepted by the Atomic Energy Commission, but also such international bodies as the World Health Organization, the International Labor Office, and the International Standards Organization.

Finally, I assure this committee most emphatically and unequivocally that so long as I am Chairman of the Atomic Energy Commission I shall not be a party to the suppression or distortion of any information bearing on the safety and health of the American public. I am fully prepared to assist any competent body in developing the facts now in controversy on the fallout issue and to disclose these facts to the public. I am confident that the Atomic Energy Commission has not been derelict in its duty in studying radioactive fallout and in revealing the conclusions of such studies when the data have been collated and evaluated. If, however, your committee finds any shortcomings on the Commission's part, I pledge you to initiate immediately the most vigorous and comprehensive corrective measures possible.

REPORT TO THE SURGEON GENERAL

U. S. PUBLIC HEALTH SERVICE

ON

THE CONTROL OF RADIATION HAZARDS IN THE UNITED STATES

PREPARED BY

THE NATIONAL ADVISORY COMMITTEE ON RADIATION

MARCH, 1959



## NATIONAL ADVISORY COMMITTEE ON RADIATION

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## I. FOREWORD

The National Advisory Committee on Radiation was formed in 1958 by the Surgeon General of the U. S. Public Health Service, to provide him guidance in matters pertaining to the control of radiation hazards in the United States. Among the many assignments which have been given the Committee since its inception, one has been the task of evaluating the programs currently followed in this country to protect the health and well being of the public from the hazards of ionizing radiation. This report presents the conclusions reached by the Committee after its study of this important subject.

## II. RADIATION HAZARD, A PROBLEM IN PUBLIC HEALTH

During the past several years, a number of scientific bodies, including the National Academy of Sciences of the United States<sup>(1)</sup> and the United Nations Scientific Committee on the Effects of Atomic Radiation<sup>(2)</sup>, have reported extensively on the influence of ionizing radiation on biological systems. From these reports it is evident that serious health problems may be created by undue radiation exposure and that every practical means should be adopted to limit such exposure both to the individual and to the population at large.

The principal sources of ionizing radiation which have been created or developed by man include x-ray machines, nuclear reactors and their radioisotopic byproducts, high-energy particle accelerators, a number of concentrated forms of naturally occurring radioactive materials, and the fallout constituents of nuclear weapons. Among these sources, only nuclear reactors, their fuels, their radioisotopic byproducts, and their radioactive wastes have been placed under substantial regulation from the standpoint of their influence on health and safety. This is notwithstanding the fact that



extensive studies have revealed that most of the ionizing radiation received by the population today, other than that received from natural sources, has been from the x-ray machines employed by the health professions. Concerted effort is now being applied by these professions to reduce, as far as is possible, the exposure of individuals undergoing x-ray diagnosis and treatment. Even so, the absence of a comprehensive program through which the health hazards of all sources of ionizing radiation may be brought under supervision appears to this Committee to be an important weakness in this nation's efforts to control radiation safely.

A comprehensive program of radiation control appears particularly important at this time in view of the increasing breadth of human activity wherein ionizing radiation is a significant health hazard. X-ray machines are now used extensively in industry as well as in the health professions. Radioisotopes are finding application in a rapidly increasing number of industrial plants, university laboratories, hospitals and agricultural research centers. And nuclear reactors are being planned and constructed at an accelerating pace. Few areas of human activity remain where sources of ionizing radiation do not find some practical application.

Since the discovery of x-rays in 1895, the radiation exposure of the population has been gradually increasing. This is shown in table I where the annual whole-body dose of radiation received externally by an average individual of the United States from natural and x-ray sources is estimated for the period from 1925 to 1955. The data were derived from material included in the report of the United Nations Scientific Committee<sup>(2)</sup> and from

calculations based on estimates of the x-ray film consumption of the country during this time period<sup>(3, 4)</sup>. The continued upward trend exhibited by the x-ray data suggests the likelihood that the current exposure of the population from x-ray apparatus may increase still further unless appropriate radiation control measures are systematically applied.

TABLE I. Estimated Annual Whole-Body Dose in Millirems Received Externally from Natural and X-ray Sources

| <u>YEAR</u> | <u>NATURAL SOURCES</u> | <u>X-RAY SOURCES</u> |
|-------------|------------------------|----------------------|
| 1925        | 100                    | 15                   |
| 1935        | 100                    | 40                   |
| 1945        | 100                    | 75                   |
| 1955        | 100                    | 135                  |

The radiation exposure received from atomic sources is also likely to increase with the passage of time. This is well demonstrated in table II, where the national growth in nuclear power capacity is predicted for the years 1965 through 1995. The table also includes estimated values of the accumulated volume of radioactive waste which may be expected to result from this nuclear power development<sup>(5)</sup>.

TABLE II. Predicted Power Capacity and Accumulated Volume of Radioactive Waste Resulting from Development of the Nuclear Power Industry

| <u>Year</u> | <u>Power Capacity<br/>(megawatts)</u> | <u>High and Intermediate Level<br/>Waste Products (gallons)</u> |
|-------------|---------------------------------------|-----------------------------------------------------------------|
| 1965        | $1.5 \times 10^4$                     | $1.5 \times 10^6$                                               |
| 1975        | $8 \times 10^4$                       | $2 \times 10^7$                                                 |
| 1985        | $2 \times 10^5$                       | $8 \times 10^8$                                                 |
| 1995        | $5 \times 10^5$                       | $2 \times 10^9$                                                 |

Another measure of the growth to be anticipated in the field of atomic energy may be made from an examination of the actual growth which has taken place during the last few years in the use of radioisotopes in the United States. This is shown in Table III, where the quantity of radioisotopes shipped from the Oak Ridge National Laboratory from 1952 to 1958 and the number of medical users of radioisotopes in the United States in a similar period are tabulated<sup>(6, 7)</sup>.

Table III. Curies of Radioisotopes Shipped by Oak Ridge National Laboratory and Number of Medical Users of Radioisotopes in the United States

| <u>YEAR</u> | <u>Curies</u> | <u>Number of Users</u> |
|-------------|---------------|------------------------|
| 1952        | 12,000        | 445                    |
| 1954        | 30,000        | 870                    |
| 1956        | 100,000       | 1533                   |
| 1958        | 230,000       | 1935                   |

In addition to the rapid, anticipated growth in the use of devices and products which produce ionizing radiation, there is another factor which urgently points to the nation's need for a comprehensive program governing the public health aspects of this radiation. This is the increasing respect given by scientists to radiation exposure as demonstrated by the steady downward revision, made over the past thirty years, in the maximum permissible levels of ionizing radiation recommended by the National Committee on Radiation Protection and other authoritative groups (Table IV)<sup>(8, 9, 10, 11, 12)</sup>

Each downward revision increases the responsibility of those concerned with the problems of radiation protection.

Table IV. Recommended Annual Maximum Permissible Dose in Rems for Workers Occupationally Exposed to Ionizing Radiation

| <u>Period</u> | <u>Maximum Permissible Dose (Annual)</u> |
|---------------|------------------------------------------|
| 1931-1936     | 60                                       |
| 1936-1948     | 30                                       |
| 1948-1958     | 15                                       |
| 1958-present  | 5                                        |

### III. THE ELEMENTS OF A RADIATION CONTROL PROGRAM

A comprehensive program for the control of radiation hazards includes many elements; two are particularly worthy of attention:

- (a) the formulation of sound radiation protection standards and
- (b) the enforcement of public health regulations based upon these standards.

In general, the process by which a regulating agency formulates the protection standards employed in its operation consists of (1) the collection of pertinent scientific data, developed through sound research, (2) the judicious evaluation of these data by individuals whose background and training qualify them to the task, and (3) the preparation of written standards, guided by this evaluation, after due consideration of any socio-economic problems which the standards may create. Frequently the group performing the data evaluation is an organization independent of the regulatory agency.

The enforcement of health regulations by a controlling agency involves the adoption of specific procedures designed to insure that the agency's standards are honored. In the field of radiation control, these procedures include, among others, the establishment of mechanisms for the registration of radiation sources, the approval of operators and of facilities and the periodic inspection of these facilities.

It may be worthwhile at this time to examine briefly the methods currently used in the United States in the formulation of standards of radiation protection. In regard to scientific data, considerable research in radiation biology, chemistry and physics is contributing to the store of scientific knowledge needed for standards development. This research is being supported by the Division of Biology and Medicine of the Atomic Energy Commission and the National Institutes of Health of the Public Health Service as well as many other governmental and non-governmental groups. Although the magnitude of this research is substantial, a review of current scientific data, which quantitatively relate radiation dose to biological effect, indicates that many gaps exist within these data and that such gaps pose great difficulty in the establishment of many radiation protection standards on a wholly satisfactory basis. Since standards of radiation protection are of fundamental importance to programs of radiation control, it appears to this Committee that even greater emphasis must be placed on radiation research in the future. This is particularly so of scientific studies which focus directly on the provision of data for standards development. Certainly, such research should be an important component of the radiation control program now in the process of development by the Public Health Service.

Much of the responsibility for the evaluation of radiation data and the subsequent preparation of recommendations which may be used as guides by regulatory agencies in the development of their operational protection standards, has been borne in the United States by the National Committee on Radiation Protection, a private quasi-official group of internationally known American and Canadian scientists who are modestly supported in their work by the Department of Commerce. The organization deserves great praise for the untiring effort it has given on behalf of the nation for many years.

From time to time, a number of individuals and groups have suggested that the NCRP should be made a component of some specific governmental agency. They believe that, under these circumstances, the Committee would gain stature and its recommendations would benefit from the more official status given them. The National Advisory Committee on Radiation, however, believes that there is much merit in the independent position which the NCRP enjoys. In such a climate, the actions of the NCRP have been singularly forthright and decisive and it is felt that it would be unfortunate if these characteristics were changed.

#### IV. STATE VS. FEDERAL REGULATION OF RADIATION PROTECTION

The enforcement of radiation protection regulations has been the subject of considerable controversy in recent years. There are some who believe that the dangers of ionizing radiation are so great and the control of radiation hazards so complex that regulatory responsibility in this field must lie at the federal level. Others have argued that regulatory functions are

best executed at the state or local level. The following discussion reviews the controversy in an effort to resolve this difficult problem.

The Federal Government, under authority granted by the Atomic Energy Act of 1954<sup>(13)</sup>, occupies a dominant position in the field of atomic energy. Through its control of atomic fuels, production facilities, utilization facilities, facility operators, byproduct materials, classified data and patents, the Federal Government through its operating agency, the Atomic Energy Commission, exercises a profound influence over the development of atomic science in industry, medicine, and a large number of other areas within our social structure. In addition to its responsibility for the promotion and development of atomic energy, the Atomic Energy Commission has been given authority to regulate its operations and those of its contractors in such a manner that the safety of the population both individually and collectively may be maintained.

The real and potential problems imposed upon our social structure by developments in atomic energy are principally those associated with the control of the radiation, electromagnetic and particulate, created by nuclear processes. The extent of these problems goes far beyond the atomic energy production facilities. The widespread use of byproduct materials from nuclear reactors in a continuously increasing number of laboratories throughout this country poses a whole set of additional problems in radiation protection. Furthermore, the disposal of unwanted nuclear wastes of the magnitude which may be contemplated when the atomic industry is fully developed presents problems in terms of world population exposure which

are sufficiently far from a solution at the present time that many years may be expected to elapse before they fall under control.

The dual role of a single governmental agency in the promotion and development of atomic energy on the one hand and its regulation of radiation safety on the other is an interesting one. Generally, such an arrangement is unwise and may be expected to create difficulty. For example, during its lifetime, the Atomic Energy Commission on a number of occasions has been criticized for seemingly subordinating radiation safety in the interest of economy when several of its nuclear reactor installations have been planned; also, a number of individuals and groups have expressed concern over the establishment of large reactors not far from densely populated areas. Whether these criticisms have been justified or not, it is noteworthy that the dual responsibility of the Commission has been the cause of not inconsiderable misunderstanding and this may be expected to increase in the future, particularly as more and more participation in nuclear science by private groups takes place.

The question may be reasonably asked why the dual responsibilities of promotion and regulation of radiation safety were placed in a single governmental agency when the shortcomings of such a practice are so apparent. The reasons for this may be found in the history of the atomic energy development. Nuclear science began to exert a dominant role in our social structure only at the time of World War II. During this period, major effort was directed toward the development and production of nuclear weapons, an effort wholly concerned with the military establishment of our government.

Progress toward the production of practical atomic weapons was attended by the need for the rapid development of competence in the field of radiation safety and, because of secrecy, it was impractical to develop such competence in a regulatory body wholly independent of the production group. Hence, the functions of weapons development and protection regulation were administered by a single agency, the Manhattan Engineering District.

After the completion of World War II, the Atomic Energy Commission was established by the Atomic Energy Act of 1946<sup>(14)</sup>. The function of the Commission, initially, was almost wholly governmental and only relatively minor private participation in the field of nuclear science was contemplated. In view of this, the wartime responsibilities of the Manhattan Engineering District were transferred to the new Atomic Energy Commission and the dual responsibilities of promotion and regulation were carried essentially unchanged to the new organization.

When the Atomic Energy Act of 1954 was written, regulation of radiation protection was continued as a prime responsibility of the Commission in the atomic energy field. However, such regulation became immediately more complex and difficult because private enterprise was encouraged to take a vigorous role in the development of nuclear science.

The propriety of the Atomic Energy Commission to perform a regulatory function in radiation safety was soon questioned by a number of groups which believed that such responsibility is a function of state and local agencies, rather than that of the Federal Government<sup>(15, 16)</sup>. This, incidentally, is notwithstanding ample legal precedent where federal

regulatory power has pre-empted state responsibility in instances where national interest was at stake<sup>(16)</sup>.

It is not difficult to suggest examples where national interest might not be well served if regulation of radiation protection in the field of atomic energy were delegated entirely to state and local agencies. First, circumstances frequently occur where radiation hazards do not respect state and local boundaries and serious danger may be expected to develop if wider control is not provided. Furthermore, the existence of a variety of local and state radiation protection codes each with differing standards might impede the development of atomic machinery and techniques to such an extent that national interest might well be severely jeopardized. Finally, a high level of competence has been achieved by scientists associated directly and indirectly with the Atomic Energy Commission and their ability to provide the technical knowledge necessary for the execution of sound programs in radiation protection is substantial. Indeed, the performance of those so concerned constitutes a record of which the AEC may be justly proud. At the state and local levels, on the other hand, such competence is only now beginning to develop.

In spite of the foregoing, the arguments for state versus federal regulation of radiation safety are not entirely on the federal side. Although competence in radiation safety has lagged until recently in many state and local health departments and in other agencies concerned with safety problems, intensive efforts are now being made to correct this shortcoming. Evidence of this may be found in a recent survey of sixteen states, conducted by the Public Health Service, which reveals that 76 radiation health specialists

and technical assistants are currently at work in the field of radiation control in the health departments of these states. Also, history gives strong support to the concept that where regulatory controls are needed for the safety of a community, these controls may be best exercised where the authority responsible for control is not far removed from the group or groups being protected. This concept is likely to prove equally valid in the field of radiation protection for many radioactive materials used in medicine and industry, even though initially regulated, eventually become a part of environmental contamination and of necessity must be evaluated at the point of human exposure as a part of a normal health assessment program. Finally, many state and local governments have demonstrated over long periods of time that they are quite capable of operating effective control programs in important areas of human activity; for example, the record of public health authorities is difficult to surpass in the field of sanitation.

After careful consideration of the problem of states-vs-federal control of radiation safety, the Committee believes that many of the regulatory enforcement functions of a radiation control program may be discharged effectively by state and local governmental agencies. Also, the Committee believes it unwise to continue the assignment of primary authority over the public health aspects of atomic energy in the same agency that has a prime interest in the promotional aspects of the field. By this, the Committee in no way wishes to imply criticism of the Atomic Energy Commission. It merely wishes to express a principle which it believes to be fundamentally sound. Furthermore, the Committee does not wish to imply

that the AEC should not continue to pursue intensive radiation safety programs for the control of hazards in its own installations and in those of its contractors and licensees. Indeed, on the contrary, the Commission has an obligation to do so. In this respect, the position of the Commission is similar to that of many of our nation's industries which have responsibilities for the provision of a broad range of safety practices beyond those of the regulatory agencies having primary authority over the industries. However, to return to the question of where the ultimate authority should fall for decisions of policy in matters involving the protection of the public's health against ionizing radiation, the Committee believes this authority should be placed in an independent agency and preferably in one with a special interest in public health; i.e., the U. S. Public Health Service.

#### V. RADIATION SAFETY PERSONNEL

The increasing urgency for a comprehensive program of radiation protection in the United States, cited in Section II of this report, requires that there be available an ever increasing number of individuals, well trained in radiation control methods, with whom federal, regional, state and local agencies may conduct their regulatory functions. The types of individuals who are needed fall into two general categories:

- (a) radiation health specialist\* and
- (b) radiological technicians.

\* These individuals are not to be confused with health physicists, persons employed principally in industry to plan and supervise the specific radiation protection operations of the plants in which they are working.

By the term, radiation health specialist, is meant a person trained to the level of a master's or doctor's degree in the problems of radiation protection and capable of assuming a high order of responsibility in a radiation control program. This training should include advanced work in physics and the allied basic sciences, pertinent biological subjects including genetics, radiobiology, and biomathematics and practical experience in handling laboratory and field problems. By the term, radiological technician, is meant an individual trained to operate radiation measuring equipment and to conduct technical work under the supervision of a radiation health specialist.

At this time, the need for radiation health specialists appears to be most critical. Until such personnel are available in substantial numbers, programs in radiation control cannot become fully effective at any government level. Inadequately trained individuals will not be able to make the numerous judgments nor perform the complex technical operations which will be required of them.

From studies made by this Committee, it appears that the following constitute the personnel needs of the United States in the field of radiation control through the year 1970:

- (a) radiation health specialists - 1,200
- (b) radiological technicians - 4,000

These estimates are based upon the belief that approximately three to four technicians will be required for each health specialist in a nominal control program and that approximately one radiation health specialist will be needed for each 200,000 of population when the atomic

energy industry approaches full development. Future studies may, of course, alter these values.

It is anticipated that the demand for radiation health specialists will increase progressively as state and local control programs develop. At the present time, the Public Health Service and state and local health agencies have need for 150 specialists who have completed a full program of training in radiation protection. By the end of 1966, it is anticipated that these needs will have expanded to the point where 650 individuals can be profitably utilized; by 1970, it is estimated that 1,200 will be required. These figures are over and above those currently needed by the Atomic Energy Commission for the conduct of its safety programs.

#### VI. COMMENT AND RECOMMENDATIONS

It is evident from the discussions of preceding sections that radiation hazards constitute an important problem of public health. Furthermore, it is more than likely that this problem will become more difficult in the next few years.

A great deal of progress has been made in recent years toward the development of regulatory programs for the control of radiation hazards. However, even today, a number of serious weaknesses exist within current programs, as previous comments have shown. Among these may be included the absence of uniform regulatory mechanisms covering all radiation sources, an insufficient quantity of scientific data for the development of radiation protection standards, the dual responsibility for promotion and regulation of atomic energy sources currently vested in a single governmental agency, and the shortage of trained personnel with which effective radiation control



programs may be carried out. In an effort to correct these weaknesses and, more important, to improve the foundation of the radiation control programs of the United States, the Committee submits the following proposals to the Surgeon General for review and appropriate action. Specifically, the Committee recommends that:

1. Primary responsibility for the nation's protection from radiation hazards be established in a single agency of the Federal Government. The Committee believes that this agency should logically be the U. S. Public Health Service, Department of Health, Education and Welfare, and urges immediate legislation to achieve this objective.

2. The agency be granted authority for broad planning in the field of radiation control. Such planning should include the coordination of state and local regulatory programs with the safety operations of federal and private groups in a manner which will provide a unified attack on problems associated with the control of radiation hazards.

3. This agency be given authority to develop a comprehensive program of control for all sources of radiation. In this connection, the Committee wishes to call attention to the following principles and additional recommendations:

- (a) Radiation protection standards constitute a matter of broad national importance: Problems of radiation control frequently do not respect state or regional boundaries but extend across large areas of the nation. Also, the full development of nuclear science

in our society depends in no inconsiderable part on the development of uniform radiation standards which apply in all parts of the country.

Therefore, the Committee recommends that the agency be charged with the responsibility of promulgating uniform, national standards on radiation protection. In order to meet this responsibility, the agency should take full advantage of the guidance provided by the National Committee on Radiation Protection and by other organizations of similar character. Furthermore, the Committee recommends that the agency be granted authority to undertake intensive research programs aimed directly at the provision of scientific data for the development of improved standards of radiation protection.

- (b) The enforcement of regulations affecting the health and well-being of our society has traditionally been the responsibility of state and local governmental agencies. There appears to be no fundamental reasons why such agencies should not bear a substantial responsibility for the regulation of the health hazards associated with radiation exposure.

The Committee therefore recommends that as much regulatory responsibility as possible be vested

within state and local governments in the field of radiation protection. However, in order that the agency may be assured of discharging its responsibilities to the nation as a whole, the Committee recommends that the agency be granted supervening authority in those areas of enforcement where federal regulation seems more appropriate. It also recommends that this authority apply under those circumstances where a state or local government finds itself unable to meet its obligations.

Finally, in order that state and local governments may discharge their responsibilities with the greatest effectiveness, the Committee recommends that the agency be granted authority to provide technical and financial assistance to such governments, as in other public health programs.

- (c) The training of professional and technical personnel with which to meet federal, state and local requirements over the years, is a problem of national importance. Hence, the Committee recommends that the agency be granted authority to undertake a broad range of training programs which will assure that the national, state and local needs for personnel trained in radiation protection will be satisfactorily met.

## VII. PROGRAM BUDGET

It is anticipated that the cost of a comprehensive program of radiation control which includes the elements set forth in the foregoing recommendations will reach a level of approximately 50 million dollars in a period of five years. The Committee recommends, however, that the program be developed gradually perhaps at a level of approximately \$2,500,000 in the fiscal year, 1959-60, and increasing in magnitude until full development is reached in 1965. Even with such progressive staging, the Committee recognizes that the program is a substantial one. However, the criterion of realistic need has been continually before the Committee in its deliberations. There is no question that the present situation calls for bold and decisive action. With such action based upon sound principle, the Committee believes that the Federal Government should proceed with all deliberate speed.

### National Advisory Committee On Radiation

Victor P. Bond  
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 Berwyn F. Mattison  
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(Extract from Science, May 1, 1959)

## RADIATION HAZARDS POSE PROBLEMS OF HOW GOVERNMENT CAN BEST BE ORGANIZED TO PROTECT THE PUBLIC

During the past few weeks Congressmen, labor leaders, state officials, scientists, and citizens groups have voiced renewed concern about the dangers from weapon testing, the faster rate of fallout, the rising radioactivity in milk and other foods, and the growing problems of industrial radiation and atomic waste disposal. There has been particular concern as to how the Government can best be organized to monitor fallout and establish radiological health standards.

A movement is developing within the Administration and within the Congress to place primary responsibility for the nation's protection from radiation hazards in a single agency of the Federal Government. So far the Atomic Energy Commission has been chiefly responsible for work in this area. However, it is now being suggested in many quarters that the Public Health Service assume control, for there is a growing feeling that "it is unwise to continue the assignment of authority over the public health aspects of atomic energy to the same agency that has a prime interest in the promotional aspects in the field." This statement is from a recent report by the National Advisory Committee on Radiation Protection, a committee that was set up by the Public Health Service; however, none of the 12 committee members is from that agency, and only two are federal employees. The committee chairman is Russell H. Morgan, professor of radiology at Johns Hopkins Medical School.

The National Advisory Committee's report, which appeared in the 17 April issue of Science, was the culmination of a wave of criticism of the AEC's administration of the radiation control program. In response, commission chairman John A. McCone made the following statement to the Joint Committee on Atomic Energy at hearings on 29 March: "The importance of the fallout and sampling program is thoroughly recognized by the AEC and it is our intent to continue an active program. However, we have no desire to pre-empt this area of activity and if the Congress and the Executive Department wish to assign part of this activity to other Federal agencies we will cooperate with them to the fullest."

## ATOMIC ENERGY COMMISSION PROGRAM

In this fiscal year, the AEC will spend \$19 million in research associated with radiation standards and protection. In addition, \$2.6 million is being spent for sampling and analysis for national and world-wide fallout studies and \$450,000 for fellowships for training in health physics, industrial hygiene, and so forth. It is expected that in 1960 the figures for radiation standards and protection will be increased to \$20 million; these funds will be provided out of a \$50-million operations budget for biomedical research. The AEC, since it was established in 1946, has used approximately \$125 million for biomedical investigations on radiation.

Some 800 scientists are engaged in this work, backed by an equal number of laboratory technicians. Research is carried out at the Brookhaven, Argonne, and Oak Ridge laboratories, at the University of California's Lawrence and Los Alamos laboratories, and through contract with 204 universities and 19 corporations.

Arrangements for the exchange of information on sampling and of other fallout data exists between the AEC and a number of other federal offices, such as the Weather Bureau, the Department of Agriculture, the Public Health Service, and the Food and Drug Administration. Active sampling programs are being conducted in a number of countries with which the AEC exchanges information. These countries are widely dispersed over the world and include, for example, Japan, New Zealand, Norway, England, and Brazil. In addition to conducting a world-wide atmospheric sampling program, the commission has 64 soil-sampling stations in foreign countries and 17 in the United States.

## PROJECT SUNSHINE

No comprehensive up-to-date account of all the AEC's radiation control work is available, nor is it possible to obtain a clear-cut description of Project Sunshine, the commission's chief program dealing with the large-scale distribution of radioactivity. Sunshine was set up secretly in 1953, at the suggestion of AEC Commissioner Willard Libby.

shifted to a study of the fallout from weapon tests, particularly of strontium-90.

The work is under the supervision of the Division of Biology and Medicine, which is headed by Charles A. Dunham. Forest Western is his assistant director for radiation protection. When asked recently to outline the scope of Project Sunshine, Western answered: "Unfortunately I can't answer, for the project has never been defined." He then went on to explain that when Sunshine was established, the division already had an extensive program of research on the biological aspects of radiation—some of it especially concerned with the hazard question, some not. This work continues today. Western pointed out that this separate research program has resulted in a complicated overlapping of activities that has sometimes led to confusion in connection with Sunshine.

Recently there has been criticism of the AEC because no one person is solely responsible for Project Sunshine. In answer to a question about this, Western said that the commission had been unable to recruit any of the men it had selected.

#### ATMOSPHERIC RADIOACTIVITY STUDIES

Joshua Z. Holland, meteorologist and a biology division member who devotes all his time to fallout problems, recently described one major aspect of the AEC's fallout work with commendable simplicity and conciseness. He delivered a paper before the American Meteorological Society that is a synthesis of the commission's biologically motivated studies of atmospheric radioactivity. This paper is now being prepared for release as a regular AEC information report. It will be accompanied by a number of helpful charts and tables, including Table 1, shown here, which outlines the fallout sampling networks that provide the bulk of the AEC-sponsored measurements of radioactivity in the atmosphere and in precipitation.

#### SAMPLING METHODS

In Table 1, where the AEC is listed alone, this indicates that the entire project—both the collection and the analysis of samples—is under the supervision of the Health and Safety Laboratory (New York Operations Office); where the AEC is listed jointly with another agency, that agency is responsible for the collection and the Health and Safety Laboratory is responsible for the analysis. All of the data from the various programs noted in the table are eventually sent to the Weather Bureau, which conducts comprehensive studies and makes worldwide graphs and so forth. Lester Mucha heads this work.

TABLE 1.—Data from Atomic Energy Commission fallout monitoring networks

| Type of sample                    | Operating agency | Number of stations | Frequency of sampling | Geographical extent  | Analysis                                                                                                                                                                       |
|-----------------------------------|------------------|--------------------|-----------------------|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Gummed film                       | AEC              | 197                | Daily                 | Worldwide            | Total beta radiation                                                                                                                                                           |
| Precipitation in pots and funnels | AEC              | 57                 | Monthly               | Worldwide            | Sr <sup>90</sup> , Sr <sup>91</sup> , Wm, total beta radiation                                                                                                                 |
| Precipitation in wash tubs        | AEC              | 4                  | With each rain        | U.S. and New Zealand | Sr <sup>90</sup> , Sr <sup>91</sup> , (U.S.), Cs <sup>137</sup> (N.Z.), Ba <sup>140</sup> , Wm, total beta radiation                                                           |
| Other                             | AFRCR*           | 6                  | Biweekly              | 76° N to 41° S       | Sr <sup>90</sup> , Ba <sup>140</sup> , Wm, Pb <sup>210</sup> , H <sup>3</sup>                                                                                                  |
| Other                             | PHS†             | 44                 | Daily                 | U.S.                 | Total beta radiation                                                                                                                                                           |
| Other                             | USGS†            | 3                  | Biweekly              | N. America           | H <sup>3</sup>                                                                                                                                                                 |
| Soil                              | USDA-AEC         | 87                 | Every 2 years         | Worldwide            | Sr <sup>90</sup>                                                                                                                                                               |
| Soil                              | AEC              | 17                 | Every year            | U.S.                 | Sr <sup>90</sup>                                                                                                                                                               |
| Surface air                       | NRL†             | 28                 | Daily                 | Worldwide            | Daily: total beta radiation; monthly: Sr <sup>90</sup> , Sr <sup>91</sup> , Y <sup>90</sup> , Cs <sup>137</sup> , Co <sup>60</sup> , Co <sup>58</sup> , Pb <sup>210</sup> , Wm |
| Surface air                       | PHS†             | 44                 | Daily                 | U.S.                 | Total beta radiation                                                                                                                                                           |
| Upper air                         | USAF-AEC         | 4                  | Monthly               | 45° N to 23° S       | Sr <sup>90</sup> , Sr <sup>91</sup> , Zr <sup>95</sup> , Cs <sup>137</sup> , Ba <sup>140</sup> , Co <sup>60</sup> , Wm, Rh <sup>106</sup> , total beta radiation               |

\* Air Force Cambridge Research Center (with partial AEC support); † U.S. Public Health Service; ‡ U.S.

The table indicates several sampling methods. The gummed film collector mentioned consists of a square foot of cellulose acetate film coated with rubber-base cement. Two of these are exposed at each station per day. At the end of the collection period, the films are folded and mailed in a preaddressed envelope to the Health and Safety Laboratory. The people who do this collecting are volunteers; the AEC does not have teams in the field for this work.

It has been found that fallout collectors that retain precipitation, while not providing such convenient samples for counting, collect more radioactivity per unit area than does the gummed film. In fact, it appears that most of the strontium-90 fallout is brought down by rain and is not retained by gummed film. Therefore, 1-foot stainless steel pots have been used as collectors. Samples are transferred to polyethylene bottles and mailed in. The pots are now being replaced by a new collector consisting of a funnel and simple ion-exchange column that will facilitate and standardize the sample-handling procedure.

Air filter samplers are also widely used to collect airborne dust. These are an essential part of local industrial radiation protection programs.

Soil sampling is the best measure of the total strontium-90 which has fallen per unit area of earth's surface. However, analysis of bulky samples is far more difficult than analysis of the more concentrated types of samples. Lyle Alexander of the Department of Agriculture's Bureau of Plant Industry is in charge of the chief soil survey, which is international in scope.

#### ENVIRONMENTAL RADIOACTIVITY STUDIES

Hal L. Hollister, a physicist, is the other person in the Division of Biology and Medicine who works full time on fallout; his province is environmental contamination. The commission has many projects in this area. For example, a pasture survey for the analysis of plants, soil, whole animals, bone, and milk is being conducted by the Health and Safety Laboratory in cooperation with the Department of Agriculture. Ocean sampling programs are being carried out at Stanford University, the University of Washington, the Woods Hole Oceanographic Institution, the University of Miami, the University of California's Scripps Institution for Oceanography, and the Lamont Geological Laboratory of Columbia University. The last also has a program to study strontium-90 in human bone. The bones of cadavers are contributed by cooperating groups all over the world.

At the Los Alamos Scientific Laboratory there is a program to determine whole-body concentrations of cesium-137; everyone who visits the laboratory is checked. In addition, the laboratory conducts a milk survey under which powdered milk is collected at many points in the United States and Canada. And finally, there are various food analysis projects, although an AEC spokesman commented that these are "not very systematic."

#### Public Health Service

Since the discovery of the x-ray 50 years ago, the Public Health Service, as the principal federal health agency, has been concerned with radiation hazards and has engaged in the compilation and distribution of data on radiation and the investigation of accidents and other activities. In the 1930's, for example, the PHS participated in the investigation of radium poisoning in workers who painted dials in watch factories. During World War II, staff members worked with personnel at the Manhattan District in establishing standards for radiation tolerance.

In 1945, the Division of Tuberculosis set up and published radiation standards for photofluorographic technicians. Both the National Institutes of Health and the Bureau of State Services initiated training programs in 1948 to increase the technical competence of PHS personnel, and in the same year a Radiological Health Branch was set up with a budget of \$17,638.

By 1955, the program had expanded to include 39 positions and a budget of \$260,000. During the previous 7 years, the Service had undertaken studies of stream characteristics of the Columbia River Basin near the Hanford atomic energy works and a study of hazards to uranium miners on the Colorado plateau. It had also started radiological training activities at the Robert A. Taft Sanitary Engineering Center in Cincinnati. In 1953, the Service began collaborating with the AEC in the off-site monitoring of weapon tests.

In 1956, the Surgeon General established a series of staff studies to determine more precisely the nature of the radiological public-health problem and the role of the PHS. The fundamental problems, it was agreed, were those of determining more precisely the tolerance levels of radiation exposure, developing means of protecting human beings from unnecessary exposure, and disseminating information to members of the public health profession and the public.

On 5 February 1958 Arthur S. Flemming, Secretary of Health, Education, and Welfare, approved the establishment of a Division of Radiological Health in the Bureau of State Services. In February of this year, the Surgeon General also established the National Advisory Committee on Radiation, mentioned earlier, to advise him and the newly established division.

#### RADIOLOGICAL HEALTH BUDGET

The Division of Radiological Health, with Francis J. Weber as chief, began operating last July. For fiscal 1958, the budget was \$390,000; for 1959, it is \$608,000. The staff has been expanded to 76 persons.

A principal activity of the division is the training of personnel in the technical aspects of radiation in relation to health. In 1958 the Service offered short topical courses to 351 personnel from states and communities. Nine of these courses are being conducted this year.

To date, 43 stations have been set up for the measurement of radioactivity in the air, 45 stations for testing water, and 10 for sampling milk. Samples are analyzed once a month, and the methods used have been sent to state health departments.

On 16 March Flemming held a news conference to discuss radiation problems. As background for the Public Health Service's present interest in the field, he reminded his audience that it was the PHS that several years ago advocated the abolition of x-ray machines for fitting shoes and that last year proposed the substitution of skin tests for mass x-ray surveys as the first step in detecting tuberculosis.

He then went on to describe Department of Health, Education, and Welfare plans for 1960 for the Public Health Service. The department's budget for 1960 calls for slightly more than a doubling of the capabilities of the PHS in the field of radiation. The request is for an appropriation of \$1,439,100, an increase of \$805,000 and the largest single increase within the Service. This is in addition to the some \$2 million being devoted to the study of radiation by the National Institutes of Health through grants-in-aid and in its own laboratories. The expanded PHS effort would be made in three categories—research, technical assistance to states and communities, and training of personnel. The research proposed would include studies of two types of population groups—individuals exposed to radiation in industry and individuals exposed in the course of medical diagnosis and therapy. In addition, the research would seek to simplify and standardize tests used to measure radiation levels.

On 3 April, just a few days after the release of the report of the National Advisory Committee on Radiation, the White House announced that the President had asked that a special study of the administration of the radiation control program be conducted by the Bureau of the Budget. Among the problems the study will consider is whether the principal responsibility for protecting the public against the effects of radiation should remain with the Atomic Energy Commission or be transferred to the Public Health Service. Participants in the survey include the leading officials of the two agencies chiefly concerned—John A. McCone of AEC and Arthur S. Flemming of HEW. A report of the Budget Bureau's investigation is expected soon, for on 5 May the Congress' Joint Committee on Atomic Energy will open hearings on the issue.

[Article from the New York Times, Mar. 29, 1959]

FALLOUT SURVEY HELD MAKESHIFT—AEC SPURS "URGENT" REVIEW OF SPLIT AUTHORITY AND "CONFUSION" IN RESEARCH

By John W. Flinney

WASHINGTON, March 28.—The Atomic Energy Commission has no one directly in charge of its program for measuring the extent and hazards of atomic fallout.

There are only two persons within the Commission working full time on the fallout research program, known as Project Sunshine.

This lack of clear authority and direction over the Commission's multi-million-dollar study of fallout is looming as one of the major problems facing the Commission as it seeks to defend its radiation research program against criticism from the administration and Congress.

John A. McCone, Chairman of the Commission, was reported to be looking into the organization of the fallout research program "on an urgent basis" with a view to establishing clear-cut authority and direction.

#### SETUP CALLED MAKESHIFT

The present organization of Project Sunshine, which one key official frankly described as "makeshift," has thus far gone unexplored in the congressional criticism and administration reappraisal of the fallout program.

Until now the congressional criticism has centered on charges that the Commission was suppressing fallout information. The accusation has been emphatically denied by President Eisenhower and Mr. McCone.

Within the Commission the concern is not so much over the extent of the radiation research program, which Mr. McCone has described as "extensive and elaborate," but rather over its administration. As one official put it, "our problem is not suppression but administrative confusion."

The Commission's concern over the administration of Project Sunshine is reflected in the fact that for several years it has been trying vainly to find a scientist to head the project.

#### AUTHORITY DIVIDED

Responsibility for directing Project Sunshine is somewhat indistinctly divided between Dr. Willard F. Libby, a scientist on the Commission, and Dr. Charles L. Dunham, Director of the Commission's Division of Biology and Medicine.

As a pioneer in the study of fallout, Dr. Libby has continued an active interest in the problem while on the Commission. As he told a reporter, he has had "a great deal to say" about what research was done on the distribution of fallout, although he has not been "in direct charge" of the research.

The medical biological aspects of fallout—or what happens once it enters the human body—have been handled largely by Dr. Dunham as part of the responsibilities of his Division.

Both officials conceded in separate interviews that it was impossible for them, because of other duties, to pay full-time attention to the fallout problem. Dr. Dunham, who is in charge of a division spending \$43 million a year, estimated, for instance, that he could spend about one-third of his time on Project Sunshine.

Within the Biology and Medicine Division two scientists are working full time on the fallout problem. They are Joshua Z. Holland, a meteorologist acquired from the Weather Bureau, and Hal L. Hollister, a physicist who directed the exhaustive study of fallout conducted in 1957 by the Joint Congressional Committee on Atomic Energy.

Neither scientist has specific authority to direct the fallout project. Mr. Holland specializes in research on the global distribution of fallout. Mr. Hollister, following the congressional investigation, was made Dr. Dunham's adviser on the overall fallout problem.

Dr. Dunham told a reporter that it would be "very definitely desirable" to have a scientist in direct charge of Project Sunshine. He pointed out, however, the Commission's lack of success so far in finding a scientist willing to leave his laboratory and take over the specialized project.

#### TRANSFER PLAN REJECTED

For a time, Dr. Dunham said, the possibility of turning over Project Sunshine's direction to one of the Commission's national laboratories was considered. However, it was decided that the administration and direction of the project should remain under the direct control of the commission, he said.

In the last few years, particularly since the 1957 congressional hearings, Project Sunshine has grown into one of the commission's most elaborate, far-flung research programs.

Project Sunshine was started in 1953 when the Rand Corp., at the suggestion of Dr. Libby, called a group of scientists together at Santa Monica, Calif., to study the fallout from atomic weapons. From the sunny site of the conference was derived the name of the project—a name that since then has been an embarrassment to the commission.

Originally Project Sunshine was a secret study of the fallout that could be expected in an atomic war. With the 1954 hydrogen bomb tests in the Pacific, which spread radioactivity over thousands of square miles, the emphasis shifted to a study of the fallout from weapons tests. The creation and distribution of radioactive strontium became a major study.

Originally there were two Sunshine laboratories. One was Dr. Libby's at the University of Chicago, which developed methods for analyzing the radioactive materials of fallout. The other was the Lamont Geological Laboratory in New York, which concentrated on the depositing of strontium in human bones.

Now Project Sunshine is spread through hundreds of laboratories, hospitals, and collection stations throughout the world. With the commission's support, hundreds of scientists and technicians are studying every aspect of fallout from its worldwide distribution to its being absorbed into plants and food and the effects of the radioactivity on man.

#### WORLDWIDE TESTS MADE

In the current fiscal year the commission is spending \$2,500,000 for the sampling and analysis of national and worldwide fallout. In addition, it is spending \$18 million for biological and medical research on radiation effects and protection. Much of this research contributes directly or indirectly to Project Sunshine.

In the opinion of some commission officials, a serious problem has arisen in coordinating and directing all this research and in disseminating the results of the research among scientists engaged in the fallout project.

As pointed out by these officials, the Division of Biology and Medicine, which sponsors much of the research, is interested in the results from the standpoint of the biological effects of radiation. Consequently, it is pointed out, there is little incentive within the division or authority from outside to make certain that scientists engaged in fallout studies are kept informed of new developments.

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#### THE FALLOUT PROBLEM

It is an example of the interaction between the advances of science and the conditions of society.

(Barry Commoner\*)

Not so long ago the impact of science on society was a process to be demonstrated by scholarly research. In the last two decades, however, the effects of rapidly advancing scientific knowledge on public policies have had the lively attention of those responsible for the advances, and since last October 4, this subject has won many new enthusiasts. Ten minutes of research with the morning newspaper will now convince anyone that at least two scientific subjects—investigation of nearby space and nuclear physics—have become the source of major political developments.

Recent events not only demonstrate the intimate interaction between science and social problems; they also show that this relationship is far from harmonious. It is regrettable but true that the very areas of public affairs most closely linked to scientific matters have been marked by misunderstanding, disagreement, and controversy. What has happened in recent months authenticates the warning voiced just a year ago in the report of the AAAS Interim Committee on the Social Aspects of Science: "There is an impending crisis in the relationship between science and American society. This crisis is being generated by a basic disparity. At a time when decisive economic, political, and social processes have become profoundly dependent upon science, the discipline has failed to attain its proper place in the management of public affairs" (1).

My purpose here (2) is to examine this situation as it is illustrated by one of the more troublesome issues: the long-range effects of worldwide fallout from tests of nuclear weapons.

\*Dr. Commoner is professor of botany at Washington University, St. Louis, Mo. This article is based on a paper presented at the symposium on radiation hazards of the AAAS Committee on the Social Aspects of Science held at the Indianapolis meeting of the AAAS, Dec. 29, 1957.

#### FALLOUT

The fallout problem results from the decision on the part of three governments to carry out a particular type of military activity: test explosions of nuclear weapons. It is reasonable to expect these governments to determine that nuclear tests shall not cause inadmissible hazards to human life. This responsibility requires: (i) determination of the need for, and the advantages to be derived from, the nuclear operations; (ii) estimation of the extent and character of the hazards; and (iii) a judgment of the relative weights of the advantages and hazards.

In an orderly state of affairs we expect scientists to produce an evaluation of possible dangers sufficiently clear and sufficiently close to being unanimous to provide a workable basis for decision. We expect the makers of policy to reach a conclusion which represents a balanced evaluation of needs and hazards. We expect the public to be sufficiently informed about the needs and possibly harmful consequences to understand and support this judgment.

This is the ideal. What is the reality?

That governments find advantage in conducting test nuclear explosions may as well be taken here as a fact of political life. It is not our purpose at this time to debate the validity of this need.

As to the scientific aspects of the possible health hazards of fallout, we are fortunate in having the extensive report of the hearings that the Joint Congressional Committee on Atomic Energy held in June 1957, which is now available in two printed volumes of some 2,000 pages each (3). This report contains the best available summary of the facts, estimates of the variability of the pertinent data, and discussions of the theoretical considerations which bear on the question. The chief facts may be summarized as follows:

Radioactive isotopes contained in the fallout produced by past nuclear tests are being spread throughout the world and increase the radioactivity received by every person on the earth. Since the isotope of chief concern, strontium 90, is relatively long-lived, fallout radioactivity will be perceptible for a few generations even if no further tests occur. Fallout adds to the burden of radioactivity from natural sources, and from medical treatment, to which persons are exposed. Where the relatively low levels of natural radioactivity appear to be agents of disease (as in the case of genetic defects and, probably, leukemia and bone tumors), we may expect the incidence of disease to increase as a result of fallout. The average increased incidence of disease due to fallout from tests conducted thus far will be small (of the order of 0.2 to 2.0 percent) compared with the natural incidence. However, since fallout affects the entire population of the world, the absolute numbers of persons who may become diseased because of its radioactivity are not small. Thus, estimates reported at the congressional hearings indicate that fallout from past tests may account for the birth of from 2,500 to 13,000 genetically defective children and for 25,000 to 100,000 cases of leukemia and bone tumor (considered together) during the next generation. The damage expected from fallout will in most cases not occur until a minimum of about 10 to 30 years has elapsed, and often it will be much later. When the damage does occur it will ordinarily be impossible to distinguish between an effect of fallout and effects of natural radiation or other factors. Moreover, any numerical estimate of the average increase in disease incidence expected from fallout must be accompanied by a very large probable error and is subject to considerable regional variation. Finally, the factual and theoretical basis for such prediction is sparse, contains important gaps, and is subject to divergent interpretations.

These are the facts relative to biological hazard that the policymaker must use to determine whether the testing of nuclear weapons shall continue unabated, shall be diminished, or shall be stopped entirely. How useful to this purpose are these facts?

The recent hearings of the Joint Committee give us a means of testing this question. This committee heard evidence about fallout hazards from some 50 scientists who represented a broad cross section of the scientific community, both within and outside of the Government. The committee is a group of legislators experienced in the matter of developing policy from facts provided to them by expert testimony. It appears that the evidence presented at the committee's hearing was not sufficient, in their eyes, to dictate policy. This uncertainty is summed up in the analysis prepared by the Joint Committee after the hearings were concluded, as follows: "There were differences of opinion [i.e., among witnesses] on how to forecast the consequences of further testing" (4). The analysis also states: "It is apparent, however, that the people of the



world and their governments lack information on the operational problems—meaning information that can be acted upon in a given situation—associated with fallout” (4).

Although the congressional hearings did not consider how the advantages of nuclear testing might be weighed against the estimated hazards, the evidence heard gives us a picture of the size of the problem. Anyone who attempts to determine whether or not the biological hazards of worldwide fallout can be justified by necessity must somehow weigh a number of human lives against deliberate action to achieve a desired military or political advantage. Such decisions have been made before—for example, by military commanders—but never in the history of humanity has such a judgment involved literally every individual now living and expected for some generations to live on the earth.

It is not clear who is expected to make this decision and thereby assume, in an unprecedented degree, the grave moral burden carried by those who must judge the social worth of human life. Should this judgment be made by experts with special competence? If so, where should their expertise lie? In nuclear physics, radiochemistry, biology, medicine, sociology, military strategy? On the other hand, should a responsibility of this weight be reserved to elected officials, in order to ensure that the decisions will reflect the ethical views of our society? At the moment, we seem to have no stated policy in this matter.

Finally, the present situation is also unsatisfactory with regard to the state of public knowledge on the fallout problem. This conclusion could be documented in many ways, but perhaps the most objective and significant view is that contained in the Joint Committee's summary-analysis: “Information on fallout has evidently not reached the public in adequate or understandable ways” (4).

Besides being poorly informed, the public has been confused by disagreements among scientists regarding the biological danger of present and anticipated radiation levels from fallout. The public is accustomed to associating science with truth and is dismayed that scientists appear to find the truth about fallout so elusive.

There is, it would appear, some need for improvement in the management of public affairs relative to the problem of fallout. In what follows, I shall discuss some of the reasons that may account for our present difficulties and suggest some possible remedies.

#### WHY DO SCIENTISTS DISAGREE?

Why do scientists disagree in their estimates of the biological hazard of worldwide fallout?

The scientific problem is extraordinarily difficult and complex. Its solution requires an understanding of vast interactions among masses of air, water, and soil and innumerable varieties of plants, animals, and men. Compared with our knowledge of other agencies that affect life, such as light and heat, our knowledge of ionizing radiation is recent. In the scant 60 years since the discovery of radiation, there has not been time enough for biologists satisfactorily to explore its effect on life. Strontium 90, the chief source of fallout radiation, is an element only recently made by man; there has been little time to study it in the laboratory or to analyze the consequences of its intrusion into nature. Finally, the major hazards of radiation—cancer and genetic mutation—are perhaps the most difficult unsolved problems of modern biology. Until the basic causes of these processes become more clear, the effects of radiation will be but poorly understood.

In this situation the available facts are often not sufficient to support or contradict conclusively a given explanatory idea; therefore, opposing theories will for the time flourish together. This accounts for some of the disagreement among scientists' estimates of the probable biological hazard of fallout radiation.

In part, our present troubles derive from the unequal pace of the development of physics and biology. We understand nuclear energy well enough to explode great quantities of radioactive materials into the atmosphere. But our present knowledge of biology and its attendant sciences is not adequate for contending with the difficulties that follow when the radioactive dust settles back to earth.

The remedy is apparent if not easy: more research. Witnesses at the congressional hearings as well as the earlier report of the National Academy of Sciences Radiation Committee have emphasized the urgent need for more information. The required research will be costly, and much of it needs to be

started at once, before continuing fallout permanently obscures the needed data. Following the recent hearings, the Atomic Energy Commission decided to expand its studies of fallout. But our total effort does not yet either approach the scale demanded by the whole problem or reflect sufficient participation on the part of the university laboratories concerned with basic biological research.

Another source of difficulty is that what is known about fallout hazards has not been fully communicated to the scientific community. Originally this problem arose from the association of fallout data with military operations that were closely regulated by security measures. In recent years considerable data on worldwide fallout appear to have been declassified and are now open to free communication among scientists (5). Nevertheless, the scientific community has not fully appreciated this change and still takes a gingerly approach to these areas of fact.

All scientists are aware that the spread of manmade radioactive isotopes, especially from fallout, is causing progressive changes in the radioactivity levels of air, water, soil, milk, and plant and animal tissues. Apart from the matter of possible medical hazards, this process has significant effects on various scientific endeavors, such as dating methods and isotope geology and ecology, and creates many opportunities for new insight into a broad range of terrestrial events. For these reasons, one would think that the spread of radioactivity would be followed closely by the scientific community and that data would be collated systematically with respect to location, origin, and time and published in a form easily accessible to all scientists. This has not yet been done. Of course, the Atomic Energy Commission makes numerous measurements relative to its own activities and supports projects for studying worldwide radioactivity levels in various materials. Some of the results appear in separately published reports, and in occasional papers in scientific journals. But the available information is nowhere brought together in an integrated, graphic form that reaches scientists generally—and especially those with no immediate interest in the information. Without such unified publication, gaps in the present data-gathering activities may go unnoticed and fail to attract the attention of investigators who might otherwise enter into the work.

Such gaps appear to exist. The first intensive survey of the U.S. Public Health Service has been determining radioactive pollution of air at 40 stations throughout the United States for several years. However, the Public Health Service pilot program for a nationwide survey of radioactivity in milk was begun only in April 1957. The data from this program's monthly analyses of milk from six locations in the United States have not yet been published. Comparably detailed studies of plant and animal tissues do not yet seem to be in the process of being made. Apart from intensive work by the Japanese, we seem to receive relatively little information about radioactivity levels elsewhere in the world. The Atomic Energy Commission reported receipt of the first fallout data from Soviet investigators in December 1957 (6).

The inadequacies which decisionmakers now find in basic and operational information about fallout hazards are, then, in part due to the lack of detailed, integrated, continuing data published in a form capable of enlisting the interest of the entire scientific community in this pervasive problem. We need to recall that the development of a scientific truth is a direct outcome of the degree of communication which normally exists in science. As individuals, scientists are no less fallible than any other reasonably cautious people. What we call a scientific truth emerges from investigators' insistence on free publication of their own observations. This permits the rest of the scientific community to check the data and evaluate the interpretations, so that eventually a commonly held body of facts and ideas comes into being. Any failure to communicate information to the entire scientific community hampers the attainment of a common understanding.

In sum, the fallout question has not yet become an integral part of the freely flowing stream of information which is the vehicle of scientific progress. The remedy is apparent and, for scientists, traditional: more and better publication in readily available journals. Can we not establish a systematic method of continuously reporting integrated information on worldwide levels of fallout radioactivity?

#### SOURCE OF PUBLIC CONFUSION

What is the source of public confusion on the fallout problem? In the past few years, and especially during the last presidential campaign, the public has become aware of a political cleavage on the wisdom of continued testing of

nuclear weapons. Political controversy is a natural, expected, and welcome part of public affairs in this country. What appears to trouble the public is not that political opponents have disagreed on the nuclear test issue but that the opinions of scientists have been marshaled on both sides of the debate. This appears to violate science's traditional devotion to objectively ascertainable truth.

This division is in part due to the factual uncertainties that have already been discussed, and the public concern may reflect an awareness of these uncertainties. However, this difficulty results as well from some confusion concerning the scientists' two roles in these matters. As a student and interpreter of nature, the scientist can explain to the public what consequences may result from a given policy that affects nature. As an informed citizen, the scientist has the right and the obligation shared by all citizens to form and express an ethical judgment on the wisdom of enduring that policy. Estimation of the probable damage to health that might result from the continuation of nuclear weapons tests is a scientific question. But there is, I believe, no scientific way to balance the possibility that a thousand people will die from leukemia against the political advantages of developing more efficient retaliatory weapons. This requires a moral judgment in which the scientist cannot claim a special competence which exceeds that of any other informed citizen.

The key word is "informed." Scientists as a group were the first citizens to express opinions on the wisdom of continued testing because they were naturally the first to acquire the facts about the possible hazards of fallout. It is only the lag in the spread of the necessary information to the rest of our citizens that has given the scientists their apparent monopoly on these opinions.

These observations lead to two conclusions. In the first place, scientists must take pains to disclaim any special moral wisdom on this matter. I do not mean to suggest that scientists stop expressing their opinions on this question. On the contrary, so long as the scientists remain the only group well informed about the hazards of fallout, it is essential that they form their judgments, express them, and keep the moral debate before the public. But we must not allow this issue, by default, to rest in the hands of the scientists alone. A question of this gravity cannot be handed over for decision to any group less inclusive than our entire citizenry.

The second conclusion is now self-evident: the public must be given enough information about the need for testing and the hazards of fallout to permit every citizen to decide for himself whether nuclear tests should go on or be stopped. It is the natural task of the scientists and their professional organizations to bring the necessary facts and the means for understanding them to the public. For some years the American Association for the Advancement of Science has recognized this kind of public responsibility, and scientists seem generally ready to assume it.

The National Academy of Sciences report is a good example of what can be done to inform the public about radiation generally. However, that report was only partly concerned with the fallout problem and in this respect is now outdated by the recent congressional hearings.

What we need now is to marshal the full assemblage of facts about fallout, their meaning and uncertainties, and report them to the widest possible audience. This is not an easy task. It is much simpler to publicize conclusions alone, and have them accepted not because their factual origin is fully understood but because they carry the authority associated with science.

It seems to me that we dare not take this easy way out. Unless the public has sufficient information to provide a reasonable basis for independent judgment, then oral burden for the future effects of nuclear testing will rest on some smaller group. And no such group alone has the wisdom to make the correct choice or the strength to sustain it. Unless the public is made aware of the gaps and the uncertainties in our present knowledge about fallout, we cannot expect it to support the expensive research needed to minimize them. Without public understanding and support, no Government policy can long endure.

Here then is our challenge. Can we, as scientists, with the help of our professional organizations, find a way to inform the public about these great issues? The raw material for such an educational campaign is available in the voluminous report of the congressional hearings. We can distill from this material the essential facts and ideas and bring them to the people through the media of public communication: radio and television, newspaper articles, and widely distributed pamphlets.

In sum, here are the task which the fallout problem imposes upon us. Research into the hazards of fallout radiation needs to be more fully and widely published so that the scientific community will be constantly aware of the changes which worldwide radiation is making in the life of the planet and its inhabitants. This knowledge must be at the ready command of every scientist, so that we can all participate in the broad educational campaign that must be put into effect to bring this knowledge to the public. If we succeed in this we will have met our major duty, for a public informed on this issue is the only true source of the moral wisdom that must determine our Nation's policy on the testing—and the belligerent use—of nuclear weapons.

There is a full circle of relationships which connects science and society. The advance of science has thrust grave social issues upon us. And, in turn, social morality will determine whether the enormous natural forces that we now control will be used for destruction—or reserved for the creative purposes that alone give meaning to the pursuit of knowledge.

#### REFERENCES AND NOTES

- (1) "Social Aspects of Science," preliminary report of the AAAS Interim Committee, Science 125, 143 (1957).
- (2) In connection with the preparation of this article, I thank my colleagues of the AAAS Committee on the Social Aspects of Science. I have relied considerably on ideas developed in the course of several committee meetings on the fallout problem.
- (3) "The Nature of Radioactive Fallout and Its Effects on Man," hearings before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, Congress of the United States (Government Printing Office, Washington, D.C., 1957), pts. 1 and 2.
- (4) "Joint Committee on Atomic Energy, Summary-Analysis of Hearings, May 27-29 and June 3-7, 1957, on the Nature of Radioactive Fallout and Its Effect on Man" (Government Printing Office, Washington, D.C., August 1957).
- (5) It is not clear precisely how much of the existing fallout data is now unclassified. The statement of E. A. Martell at the Joint Committee hearings indicates that cumulative fallout data up to December 1, 1955, obtained by the University of Chicago "Project Sunshine" (under contract to the Atomic Energy Commission) are reported in Bulletin No. 11, which is classified as "secret." Data for the period December 1, 1955, to August 1956 are reported in Bulletin No. 12, which is unclassified, see 3, pt. 1, pp. 617, 618).
- (6) The work of the United Nations Radiation Committee, which is in session at this writing, may be expected to lead to a considerable increase in the amount of worldwide information currently available.



## APPENDIX L

## BIBLIOGRAPHY

## RADIOACTIVE FALLOUT

Introduction

This literature search was compiled to fill a specific request by the Joint Committee. It is being issued in report form because of the general interest in its subject.

Included are 514 references on dispersal and fallout of radioactive debris from nuclear explosions. It supplements the bibliography cited in the 1957 Congressional Fallout Hearings.

The references are divided into three parts: AEC reports, non-AEC reports, and published articles. Report references are arranged alphabetically by corporate author and alphanumerically by report number. Published references are arranged alphabetically by title.

The reports referenced in the first part (AEC reports) can be examined at the AEC depository libraries listed in each issue of Nuclear Science Abstracts. They can also be purchased from the Office of Technical Services (OTS), Department of Commerce, Washington 25, D. C. A full size printed copy is available for the reports having a single price listed; other reports are available as photostat (ph) or microfilm (mf) copies. If no price is shown, a quotation may be obtained by writing OTS. In addition, microcopies of these reports may be available. Requests concerning the purchase of unclassified AEC reports in this form should be directed to the following organizations:

Microcard Foundation  
P. O. Box 2145  
Madison 5, Wisconsin

Readex Microprint Corporation  
100 Fifth Avenue  
New York 11, New York

A few of the non-AEC reports are available either from OTS (see above), from the British Information Service (BIS), 45 Rockefeller Plaza, New York, N. Y., or from the Scientific Document Distribution Office, Atomic Energy of Canada Limited (AECL), Chalk River, Ontario, Canada, but information concerning the availability of non-AEC reports generally will have to be sought from the issuing agencies.

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California. Univ., Los Angeles. Atomic Energy Project.

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General Electric Co. Hanford Atomic Products Operation, Richland, Wash.

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General Mills, Inc., Minneapolis.

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Idaho Operations Office. Health and Safety Div., AEC and Tennessee. Univ., Memphis. Coll. of Medicine.

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Knolls Atomic Power Lab., Schenectady, N. Y.

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Oak Ridge National Lab., Tenn.

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Sandia Corp., Albuquerque, N. Mex.

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Weather Bureau, Oak Ridge Tenn. and Oak Ridge Operations Office. Research and Development Div., AEC.

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Westinghouse Electric Corp. Bettis Plant, Pittsburgh.

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Non-AEC ReportsAir Force Special Weapons Center, Kirtland AFB, N. Mex.

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Atomic Energy of Canada Ltd. Chalk River Project, Chalk River, Ont., and Canada. Dept. of National Health and Welfare, Ottawa.

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Brussels. Centre d'Etude de l'Energie Nucléaire.

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