R. B. Bischoff

GENERAL ELECTRIC COMPANY

HANFORD LABORATORIES

Radiation Protection Operation for Exempt Personnel Fall 1964

AIR SAMPLING

I. METHODS OF SAMPLING

A. Inertial Collectors

1. Principle of Operation
2. Particle Size Range
3. Efficiency
4. Equipment and use

    a. Impactors

        1) Cassella Cascade
        2) Unico Cascade
        3) Staplex

    b. Impingers

        1) MSA Midget
        2) Porton

    c. Centrifuge

        1) Conifuge
        2) Goetz Aerosol Spectrometer

B. Electrostatic Precipitators

1. Principle of Operation
2. Particle Size Range
3. Efficiency
4. Equipment

    a. Bendix
    b. MSA
    c. Adley-Reciprocating

C. Thermal Precipitators

1. Principle of Operation
2. Particle Size Range
3. Efficiency
4. Commercial Equipment

    a. Cassella

D. Filtration

1. Filtration Theory

    a. Direct Interception
    b. Inertial Collection
    c. Diffusion
    d. Electrostatic Attraction
    e. Gravitational forces
    f. Re-entrainment

2. Commerical Filter Media

a. Cellulose Fiber Paper

1) Uses

b. Glass Fiber Filters

1) Uses

c. Polystyrene Fiber Filters

1) Uses

d. Membrane Fiber Filters

1) Uses

e. Mixed Fiber Paper

1) Uses

3. Filter Advantages and Disadvantages

4. HV-70 Filter Paper

a. Efficiency
b. Pu aerosol monitoring
c. Cost Comparison

II. AIR MONITORING

A. Alpha Air Monitoring

1. Coincidence Count

a. 15 MPC hours

2. Alpha Energy Analysis

a. 15 MPC hours

3. Others

B. Beta-Gamma Air Monitor

1. Fixed or Moving Tape

a. Nuclear Measurements

C. Tritium or Gas Monitors

1. Ion Chamber Devices

a. Principle
b. Limitations

III. AIR SAMPLING AND MONITORING EVALUATION

A. Purpose

1. Records
2. Entry Status
3. Trends

B. Air Sample Counting

1. Equipment

a. Scintillation (coincidence)
b. Alpha energy analysis
c. Gamma energy analysis

C. Result Evaluation

1. Lung deposition model

a. Particle Size
b. Density

IV. SAMPLING ERRORS OR PROBLEMS

A. Isokinetic Flow

1. Definition
2. Effect of Errors
3. Stack Effluent Monitoring
4. Room Air Samplers
5. In-Line Samplers

B. Calibration of Flow Rate Meters

C. Background Radiation

D. Improper Seating of Filter Media

E. Scrubber Packing and Solution Entrainment

R. L. Buschbom

RADIATION PROTECTION COURSE FOR EXEMPT PERSONNEL
FALL - 1964

Lecture	Topic	Lecturer	Dates	Time
1.	**Administrative Aspects of Radiation Protection at HAPO** A review of responsibilities for radiation protection at the different levels in an organization. Discussion of the application of the various mechanisms and techniques available for use in administration of radiation protection programs at HAPO.	L. A. Carter	9-16-64	8-10 a.m.
2.	**Legislation and Radiation Protection Trends** A review of present State and Federal legislation, including regulations for licensees of the AEC. Discussions will cover the general types of legislation which have been enacted or are proposed, and some of the pitfalls which could result from poorly-written legislation on radiation protection.	L. A. Carter	9-16-64	10-12 noon
3.	**Radiation Dose Units and Permissible Radiation Dose** Discussion of current radiation dose units, their origin and bases, and recent developments in definition and nomenclature. Review of the history of radiation protection, and the development of the concept of permissible radiation dose, including the current bases of permissible dose for both internal and external radiation.	W. C. Roesch	9-23-64	8-12 noon
4.	**Calibration of Radiation Instruments** An explanation of calibration methods. Discussion will cover radiation sources used as standards, methods of establishing standard emission from sources, use of ictoreen "R" meters, free air ionization chambers, and foil activation procedures. The adaptation of laboratory methods to routine calibration procedures will be covered. This will include consideration of scatter, energy dependence of instruments, source size and geometries, instrument response time, and calibration frequency.	C. M. Unruh	9-30-64	8-10 a.m.

Lecture	Topic	Lecturer	Dates	Time
5.	Application of Available Dose Rate Monitoring Instruments to Field Use Discussion will include consideration of the various factors involved in field monitoring practices (source sizes and geometries, RBE's, instrument capabilities, exposure standards, etc.). The adaptation of available equipment to field use will be reviewed with special emphasis on practical methods for attaining high quality measurement of radiation dose to personnel.	C. M. Unruh	9-30-64	10-12 noon
6.	Internal and External Radiation Dosimetry A discussion of methods and instrumentation available for dose measurement, with particular emphasis on those used at HAPO. The development of current HAPO dosimetry systems will be reviewed, including their capabilities and limitations.	H. V. Larson I. C. Nelson	10-7-64	8-12 noon
7.	Radiation Record Systems and Programs A discussion of the bases of the HAPO system of radiological records, the different classifications of records, the influence of quality and completeness of records, and the methods used to obtain satisfactory records. The various uses of radiological records, including their application in court cases will be reviewed.	J. M. Selby	10-14-64	8-10 a.m.
8.	Radioactive Waste Management A review of radioactive waste handling at HAPO. Discussion will cover both waste disposal and long term storage, with major emphasis on the former. The favorable influence of geological and hydrological factors on ground disposal will be included.	G. E. Backman	10-14-64	10-12 noon
9.	Effects of Radiation on Living Tissue The fundamental theories of radiobiological action at the cellular level. Discussion of primary and secondary biochemical reactions in the intact animal, genetic effects, physiological and pathological changes, modification of radiation injury, special problems of internal sources of radiation, and long-range effects such as accelerated aging, alterations in lifespan, and increased incidence of tumor formation.	B. O. Stuart	10-21-64	8-12 noon

Lecture	Topic	Lecturer	Dates	Time
10.	HAPO Programs in Radiobiology A review of past, current, and future radiobiology programs at HAPO. Discussion of pertinent findings, especially those of interest in the overall operation of HAPO.	Biology Staff	10-28-64	8-12 noon
11.	Environmental Contamination Problems and Their Evaluation Problems associated with the release of low-level radioactive effluents to the air and water of the environs, monitoring and sampling programs, important environmental factors, and evaluation of collected data. Current studies directed toward improvement of evaluations will also be discussed.	J. K. Soldat	11-4-64	8-10 a.m.
12.	Radiochemical Analysis Discussion will involve the application of current analysis techniques to measurement of radioactive material in water, air, soil, and biological samples. Both the more conventional chemical techniques and the newer gamma pulse analysis techniques will be reviewed. The influence of variables and their correction will be emphasized.	F. E. Holt	11-4-64	10-12 noon
13.	Criticality of Fissionable Materials Since sufficient amounts of fissionable materials of proper composition and configuration may become critical, even outside a reactor, a safety problem exists in the handling, processing and storage of these materials. The basic problem is one of preventing occurrence of an uncontrolled criticality in an unshielded situation during these operations. The general concepts and properties of neutron multiplying systems will be reviewed, as an introduction to the different factors which determine critical conditions. Preventing the occurrence of a critical system by control of these factors will be discussed thoroughly. Examples of nuclear safety criteria will be presented.	C. L. Brown	11-11-64	8-12 noon
14.	Radiological Hazards Analyses Evaluation of the environmental consequences of the accidental release of large quantities of radionuclides will be discussed. The various parameters bearing on such a release will be described, and the effect of the more important ones on the analysis will be examined.	E. C. Watson	11-18-64	8-10 a.m.

Lecture	Topic	Lecturer	Dates	Time
15.	Air Sampling	B. V. Andersen	11-18-64	10-12 noon

A review of available air sampling methods and equipment, with recommendations on their application. Emphasis will be on the monitoring aspects of air sampling, and adequate coverage will be given to methods of sampling, methods of measurement, and calculation of data.

Discussion will include analysis of how and where air sampling can be used effectively, the importance of air sampling in routine and emergency situations, and the position of air sampling in an overall radiation protection program. Pitfalls in installation and use of air sampling equipment will also be covered.

16.	Radiological Engineering	L. G. Faust	11-25-64	8-12 noon

Discussion will center on good design practices, and include such topics as floor plans, air flows, shielding, instrumentation, and storage and disposal of waste. Some mathematical expressions will be developed for use in shielding calculations, and the various parameters involved in evaluation of shielding requirements will be discussed. Typical illustrative examples will be presented.

LEGISLATION AND RADIATION PROTECTION TRENDS

I. TECHNICAL GUIDANCE

A. Federal Radiation Council

B. National Committee on Radiation Protection

C. International Commission on Radiation Protection

D. International Atomic Energy Agency

Federal Radiation Council
Code of Federal Regulations 10 CFR

II. TYPES OF REGULATIONS OR STANDARDS

A. Specification

B. Performance

III. FEDERAL LEGISLATION AND REGULATION

A. Atomic Energy Commission

1. AEC Manual (Contractors)

2. Title 10 Code of Federal Regulations (Licensees)

B. Interstate Commerce Commission (49 CFR 73)

IV. STATE LEGISLATION AND REGULATION

A. Transfer of Regulatory Responsibility from the AEC to the State Governments

B. States Having Completed Agreements with the AEC

C. State of Washington

V. TRENDS IN LEGISLATION

A. The Past Position of Hanford

B. Current Trends

1. Department of Labor (41 CFR 50-204)

2. AEC Manual

C. The Impact of Current Trends on Hanford

ADMINISTRATIVE ASPECTS OF RADIATION PROTECTION AT HAPO

I. RADIATION PROTECTION REQUIREMENTS

A. Contractural

B. Federal Regulations and the AEC Manual

C. Recommendations of the NCRP and ICRP

II. ASSIGNMENT OF RESPONSIBILITIES

A. Radiation Protection Operation (plant-wide responsibilities)

1. Establish basis of radiation protection program through appropriate Standards and Procedures.

2. Individual employee dose measurement and evaluation relative to established limits.

3. Reports and records of radiation protection experience

B. Operating Management (facility responsibilities)

1. Control of individual employee exposure

2. Control of sources of radiation

3. Avoidance of accidents or incidents

4. Accomplishing necessary work with minimum exposure

C. Individual Workers

1. Compliance with established rules and regulations

2. Reporting unusual conditions to supervision

D. Industrial Medical (evaluation of radiation exposure relative to health and welfare)

III. SPECIFIC AREAS OF INTEREST

A. HAPO Policies and Standards

B. Control Systems

1. Procedures

2. Operational Controls

C. Communications

1. Between Components

2. Off-Plant

D. Incidents and Investigations

1. AEC - Class A and B

2. HAPO - Class C

E. Measurements

1. External Exposure

2. Internal Exposure

3. Source Control and Release

F. Records

1. Individual Exposure

2. Area Survey

G. Technical Assistance

H. Training

9/25

RADIATION DOSE UNITS
and
PERMISSIBLE RADIATION DOSE

E.H. Reich

I. RADIATION DOSE UNITS

- A. The Two Kinds of "Dose" and Their Relation
- B. Exposure Dose
  - 1. Free Air Chamber
  - 2. Non-free Air Chambers - Bragg-Gray Principle
- C. Absorbed Dose
  - 1. From Exposure Dose Chambers, etc.
  - 2. Bragg-Gray Chambers
- D. Recent Changes
  - 1. "Exposure" and "Dose"
  - 2. Fluence
  - 3. Kerma
- E. Dosimetry for Personnel Protection
  - 1. Dose Equivalent (RBE Dose)
    - a. Quality Factor vs. RBE
    - b. Distribution Factor

II. PERMISSIBLE RADIATION DOSE

- A. History of Safety Standards
  - 1. Tolerance Doses
  - 2. ICRU, ICRP, NCRP, AEC, FRC
  - 3. Maximum Permissible Doses
  - 4. Radiation Protection Guide
- B. External Exposure
- C. Internal Exposures
  - 1. Maximum Permissible Body Burdens - Radium and Bone Seekers
  - 2. Maximum Permissible Concentration or Intake

RADIATION UNITS

Date	Scientist or Organization Responsible	Development
1895	Roentgen	Discovery of X-rays.
1896	Becquerel	Discovery of radioactivity
1897	Dorn	Air Thermometer
1901	Rutherford & McClung	Bolometer
1902	Holzknecht	Chemical dosimeter, color changes
1903	Stern	Film
1904	Sabourand & Noire	Barium platinocyanide pastilles
1905	Franklin	Ionization
1907	Guilleminot	Fluorescence
1908	Villard	Units: one esu per cc of air
1914	Szilard	Unit: one ion pair
1914	Christen	Absorbed dose
1914	Duane	Free air chamber concept*
1915	Furstenan	Resistance change
1918	Kronig & Friechich	Horn-chamber
1921	Soloman	Unit: same ionization as 1 g of Ra in 0.5 mm Pt at 2 cm
1923	Behnken	The German roentgen
1925	Glasser	Air wall chambers (Birth of the Victoreens)
1928	ICRU	Roentgen
1929	Gray	Bragg-Gray principle *
1930	Taylor	Standard free air chamber
1937	ICRU	Roentgen redefined.
1942	Parker	Units: rep, rem
1950	ICRU	Absorbed dose
1953	ICRU	Units: rad
1958	ICRU	Ad hoc committee on quantities and units
1962	ICRU	Handbook 84; fluence, kerma, dose and exposure, dose equivalent, quality factor.

MAXIMUM PERMISSIBLE DOSE

Date	Scientist or Organization Responsible	Development
1895	Roentgen	Discovery of X-rays
1896	Becquerel	Discovery of radioactivity
1898	---	Roentgen Society (British) began to collect information on injurious effects
1902	Rollins	Safe if film not fogged in seven minutes (about 10 R/day)
1915	Russ	Roentgen Society issued recommendations
1921	---	British X-ray and Radium Protection Committee formed; first report
1922	---	American Roentgen Ray Society adopted rules on radiation protection
1925	Mutscheller	Tolerance dose. Safe if less than 0.01 erythema dose per month
1925	Glocker & Kaupp	German Committee on X-ray and Radiation Protection; Mutscheller's values
1925	---	First International Congress of Radiology; ICRU formed
1925	Sievert	0.1 erythema dose per year
1926	Soloman	1/300 erythema dose per day
1927	---	Dutch Board of Health 1/70 erythema dose per day
1928	Barclay & Co.	0.00028 erythema dose per day
1928	Kaye	0.005 erythema dose per day
1928	---	ICRP formed
1929	---	U.S. Advisory Committee on X-ray and Radium Protection formed
1931		U.S. Advisory Committee, 0.2 R/day (NBS Handbook 15)
1931	Wintz & Rump	League of Nations, about 0.25 R/day for X-rays and 0.1 R/day for gamma rays
1932	Failla	0.001 erythema dose per month
1934	ICRP	0.2 R/day
1936	---	U.S. Adv. Comm. 0.1 R/day to allow for greater penetration of higher energy rays
1942	---	Metallurgical Project, 0.1 R/day
1946	---	U.S. Adv. Comm. changed to NCRP
1948	NCRP	0.3 R/week RBE's Other limits
1949	---	Tri-Partite conference at Chalk River
1950	ICRP	0.3 R/week measured in air
1954	NCRP	NBS Handbook 59. Maximum permissible dose
1957	NCRP	5 (N-18)
1959	---	Federal Radiation Council formed Radiation Protection Guides

Approximate Erythema Doses

50 KV X-rays	100 R
100 "	350
200 "	600
1000 "	1000
Radium gamma	1500

CALIBRATION OF RADIATION INSTRUMENTS

C. M. Unruh

I. Radiation Sources used for Calibrations

- A. Radium
- B. Uranium
- C. Co^{60}
- D. X-rays

II. Primary Calibration of Radiation Sources

- A. U.S. Bureau of Standard
- B. "R" Meters
- C. Free Air Ion Chamber
- D. Foil Activation

III. Routine Calibration Methods

- A. Dose Rate Instruments
- B. Detection Type Instruments
- C. Personnel Dosimeters
- D. Emergency Monitoring Equipment
- E. Special Services

IV. Visit to Calibration facility to include a first hand look at all calibration equipment and methods.

V. General question and discussion period

APPLICATION OF AVAILABLE DOSE RATE MONITORING INSTRUMENTS TO FIELD USE

C. M. Unruh

I. Why are correction factors necessary?

- A. Geometry
- B. Energy
- C. Instrument response characteristics
- D. Others

II. How does one determine correction factors?

- A. Experimentation
- B. Calculations

III. Correct methods of Interpretations for specific monitoring situations

- A. Gamma radiations
- B. Beta radiations
- C. Neutrons

IV. Improvements to be made

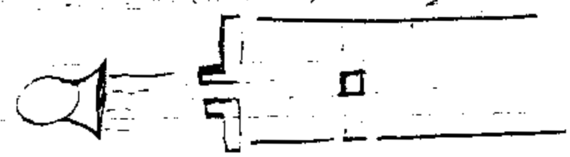
- A. New instruments
- B. Improved calibration methods

V. General question and discussion period

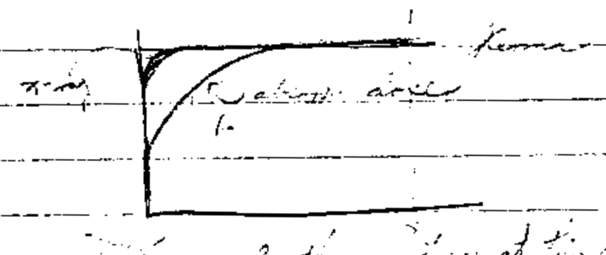
9/23/64

[illegible]

Roentgen = $\frac{1 \text{ esu}}{1 \text{ cm}^3}$



Kerma = kinetic energy of the secondary electrons released per unit mass



Unit of absorbed dose

1 Roentgen = 88 ergs/g. (Kerma in air)

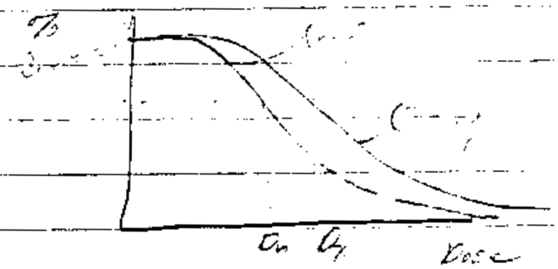
1 R = 88 ergs/g.

1 R = 97 ergs/g (Kerma in tissue)

1 rad = 100 ergs/g

RBE

$RBE = \frac{D_x}{D_n}$



Quality Factor = [illegible]

Dose Equivalent = abs. dose × Quality Factor

A REVIEW OF THE FACILITIES AND SERVICES PROVIDED BY THE INTERNAL DOSIMETRY OPERATION AT HANFORD

STATIONARY WHOLE BODY COUNTER

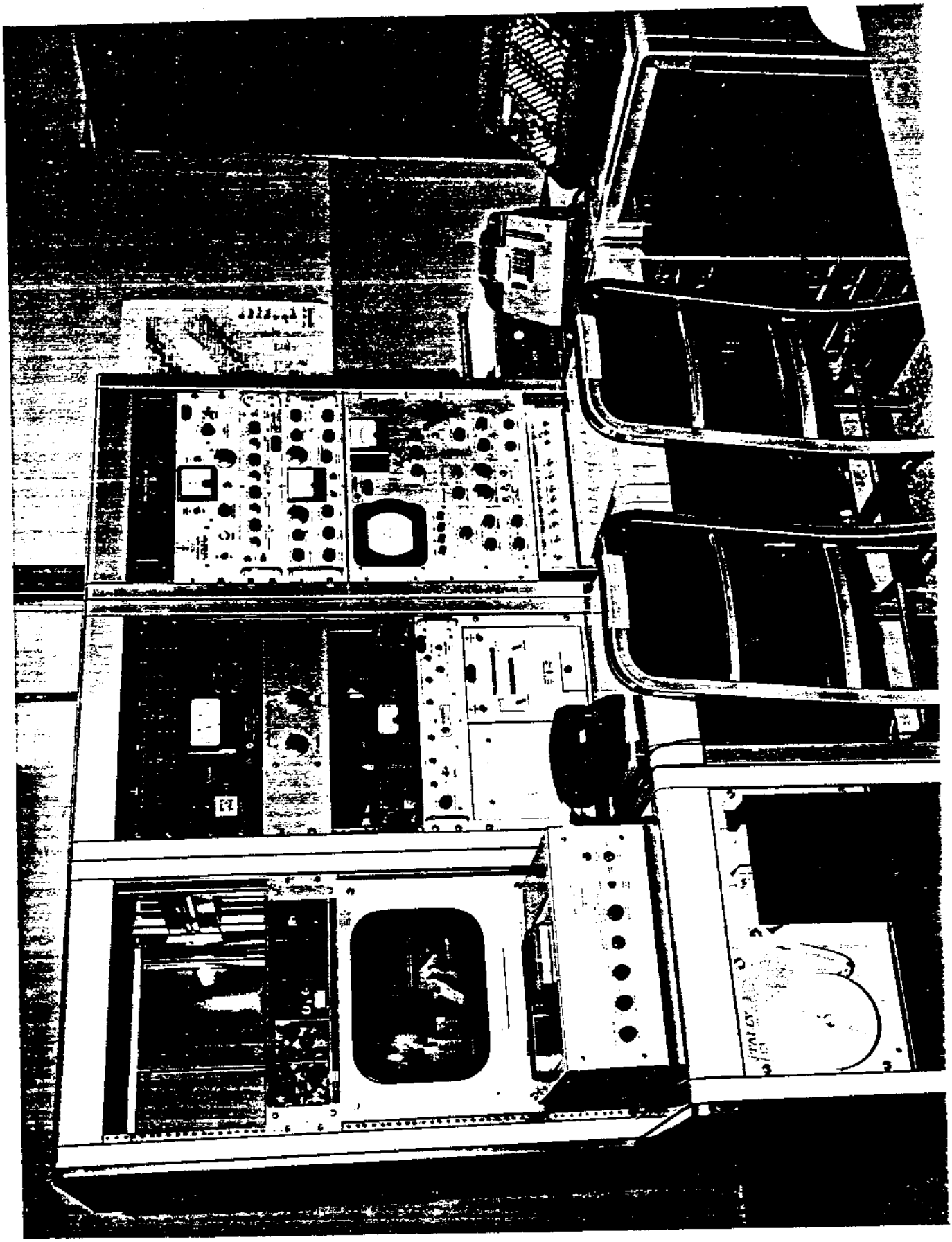
The Whole Body Counter is used both in research programs and in routine evaluation of whole body content of a wide variety of gamma-ray emitting radionuclides. With suitable crystals the unit is also used for iodine 131 evaluation in the thyroid, and quantitative measurement of plutonium deposited in superficial wounds. The unit is also capable of accurate measurement of sodium 24 in the blood, which is very useful in estimating personnel dose in event of a criticality incident.

This is a cut-away drawing of the stationary Whole Body Counter. The facilities house several locker rooms, a reception room, a counting room, an analysis room and an equipment repair shop. The heart of the Whole Body Counter is the iron room in which the measurement takes place. The room is made of 10-inch thick, steel, armor plate. The counting room is air conditioned and music is played over an intercom system. Also, a television camera was installed for viewing the patient remotely. This latter feature has proven of special value when children are being examined.

1260765

WHOLE BODY COUNTING

For routine analysis of whole-body deposited gamma-emitting radionuclides, the patient (shown in slide) sits in a reclining chair and a 9 inch by 4 inch sodium iodide crystal is placed in a geometry such that the patient's body forms an arc around the crystal. The detection limit of the crystal is about one nanocurie (for a 10-minute counting time) for most radionuclides. The crystal assembly may be placed on a track in such a geometry that the crystal can remotely scan a patient reclining on a litter. This counting geometry is used to determine the location of an isotope in the body.



1260767

WHOLE BODY COUNTER LABORATORY CONSOLE

The Whole Body Counter Laboratory Console is designed for maximum read-out capability. The heart of the system is an RIDL Model 43-12, 400 channel pulse height analyzer. Use of either two channel or four channel mixer amplifiers allows simultaneous use of one, two, three or four detectors in the iron room. Examination measurements are displayed on the analyzer scope in the form of total counts as a function of gamma-ray energy. A digital recorder permits the accumulated data to be printed out on paper tape in the form of total counts per channel. A manual address and punched paper tape system allows the data to be read out in binary coded decimal form for IBM computer calculation. A digital magnetic tape recorder may be used for spectrum stripping or storage of data to be replayed into the analyzer's memory core at a later time. Also, an X-Y plotter permits automatic graphing of data for visual inspection.

1260769

PLUTONIUM WOUND COUNTER

A wound counter is available for detecting and locating plutonium in cuts, wounds, punctures and abrasions either on or in the skin to a depth of a few millimeters. This sensitive counter consists of a 1-3/4 inch by 1 mm sodium iodide crystal and associated counting equipment. The size of the crystal permits optimum counting of the 17 kev X-ray emitted from plutonium. The detection limit of the crystal is about 0.1 nanocurie for a 10-minute counting time. The wound is located by moving a shield containing a small aperture over the suspected injury until the maximum counting rate is obtained. This detector has proved to be an invaluable tool to both the health physicist and the physician in defining sections of tissue that should be excised in order to remove the isotope from the body.

1260771

THYROID COUNTER

This slide shows a subject being examined for the presence of radioiodine in the thyroid. The detector system used is a 3 inch by 3 inch NaI crystal and photomultiplier tube mounted on the boom of a movable dolly. This arrangement allows the detector to be easily adjusted for any subject so that the crystal axis will be perpendicular to the subject's neck, just touching the clavicle. The detection limit for I^{131} with the detector in this position is 20 pc for a 30-minute counting time.

WHOLE BODY COUNTER DETECTION CAPABILITIES

NUCLIDE	DETECTION LEVEL	FRACTION OF MPBB
Cr^{51}	50 NC	5×10^{-5}
Co^{60}	0.4 NC	4×10^{-5}
Zn^{65}	0.8 NC	1.3×10^{-5}
Cs^{137}	0.6 NC	2×10^{-5}
Na^{24}	0.3 NC	4.2×10^{-5}
Fe^{59}	2.0 NC	1×10^{-4}
Na^{22}	1.0 NC	1×10^{-4}
I^{131}	20 PC (Thyroid Counter)	1.4×10^{-4}
	0.5 NC Primary Detector	3.6×10^{-3}
Pu^{239}	0.1 NC Wound Counter	2.5×10^{-3}

SIMILAR CAPABILITIES FOR OTHER GAMMA EMITTING NUCLIDES

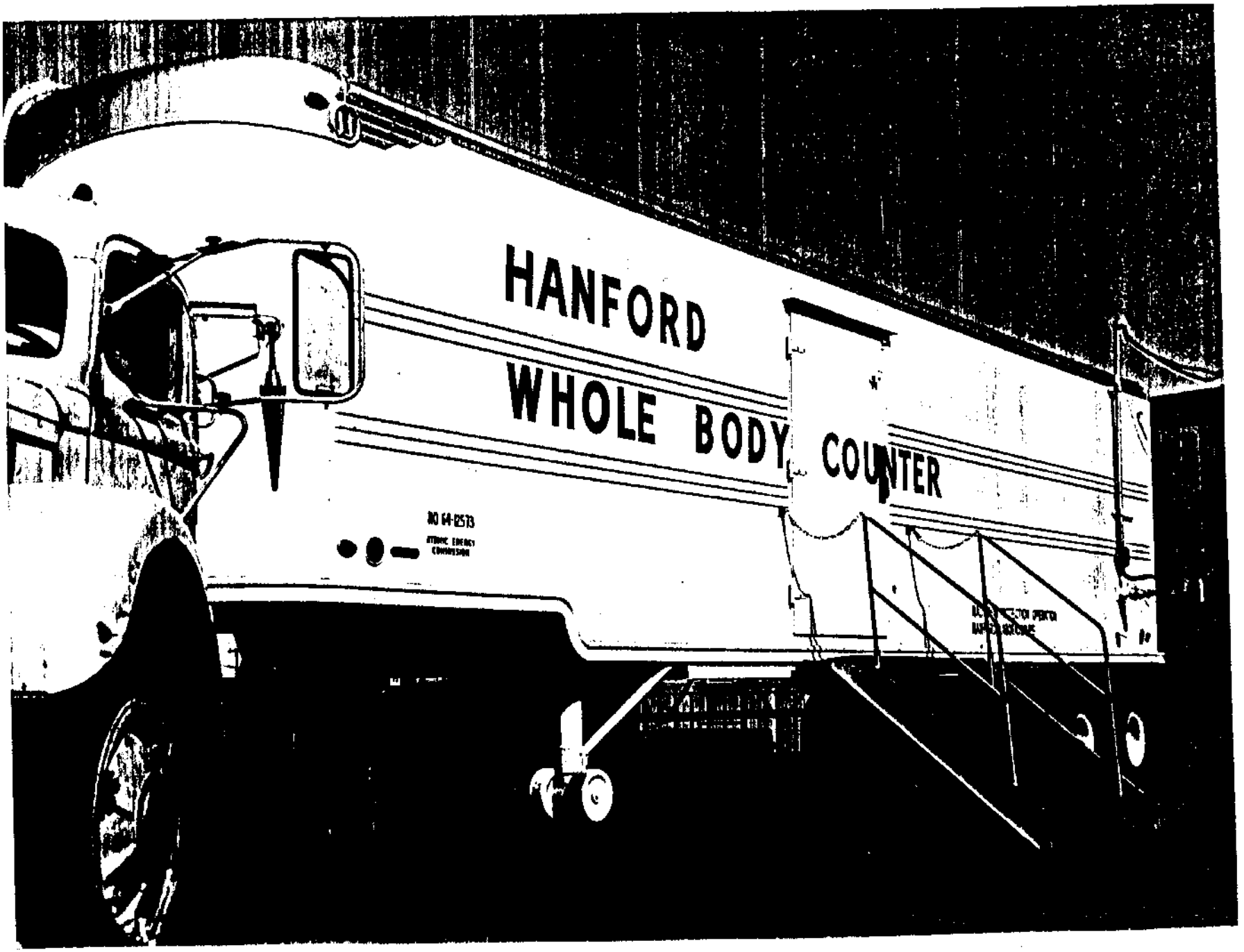
G-102-665

1260773

DETECTION CAPABILITIES

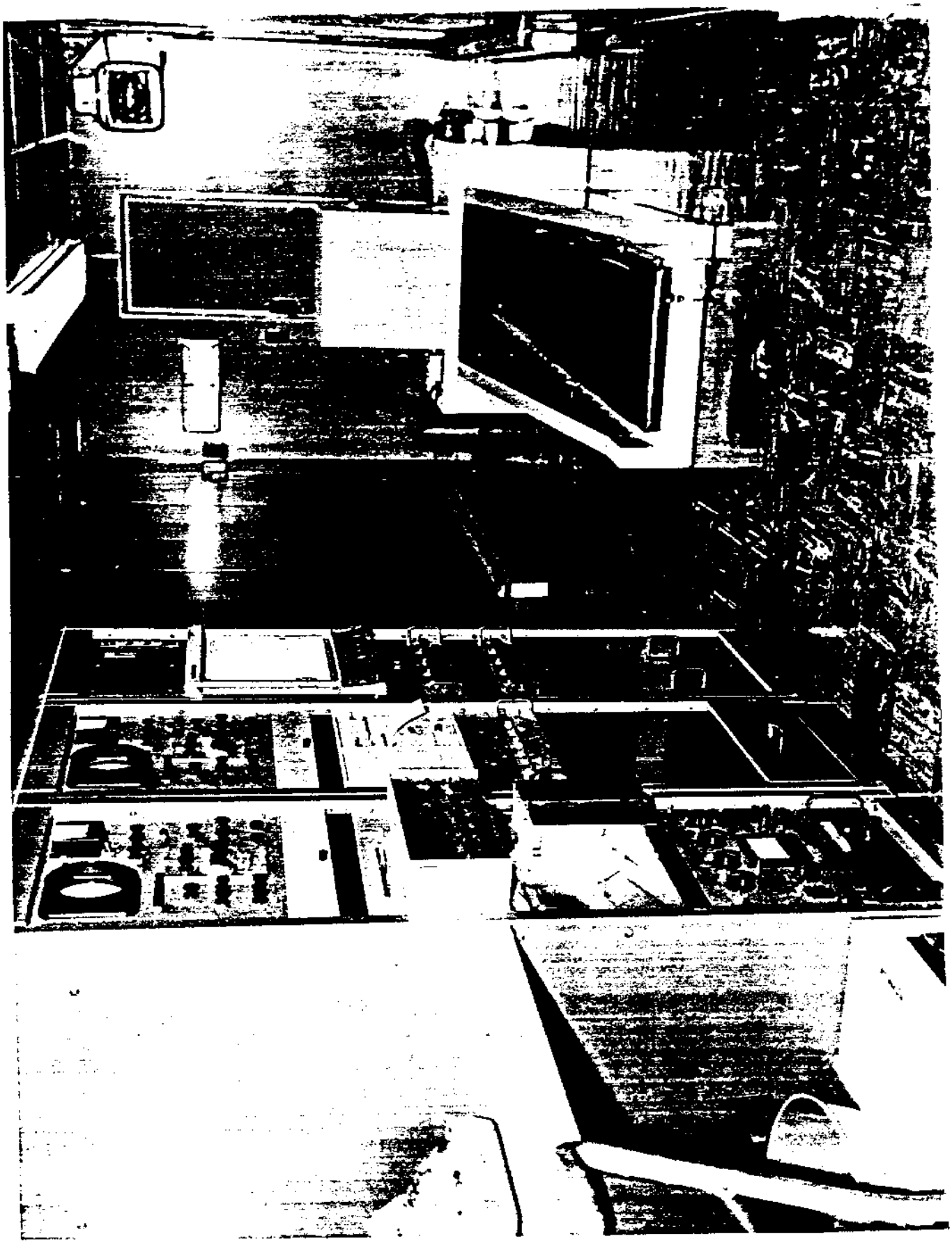
The detection capabilities of the Whole Body Counter that are shown in this slide are based upon a 10-minute counting time with the subject in the chair geometry position. In special situations, the detection levels may be lowered by longer counting times and different geometries. The listed nuclides are typical ones frequently measured in Hanford employees with the exception of I^{131} and Pu^{239}. These latter two nuclides have been measured in employees involved in on-plant radiation exposure incidents. The detection levels listed for I^{131} are based on 30-minute counting times using a 3 inch by 3 inch NaI crystal thyroid counter or a 9-3/8 inch by 4 inch NaI crystal primary detector.

Other gamma-emitting nuclides are less frequently seen, but their detection levels are comparable to those listed.



MOBILE WHOLE BODY COUNTER EXTERIOR

The Mobile Whole Body Counter is a self-contained counter laboratory housed in this semitrailer which is approximately 35-feet long, 8-feet wide and 12-feet high. Entrances are provided on the left side and rear of the trailer. The unit requires approximately 60 amperes at 220 volts, which is supplied through a cannon plug on the left side at the rear or may be taken directly from a high line through use of an adapter. The air conditioning unit is mounted on the front and a telephone cable reel is mounted underneath. The mobility of the counter permits examination of people near their work locations and in remote off-site areas. Additionally, it provides improved capability for assistance should radiological emergencies occur.

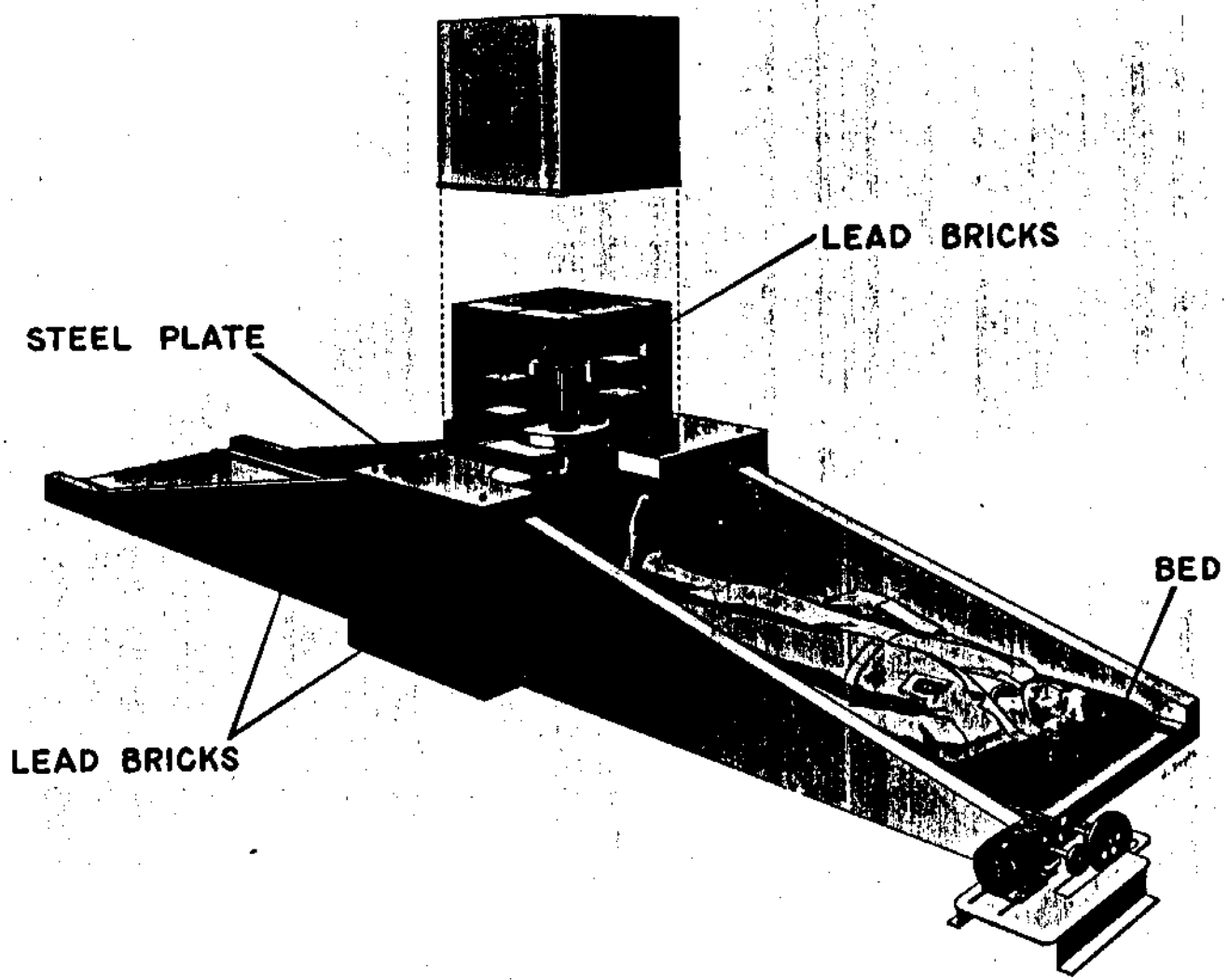


1260777

MOBILE WHOLE BODY COUNTER INTERIOR

The interior of the Mobile Whole Body Counter is supplied with air conditioning, fluorescent lighting and electrical baseboard heating. The left side has a counter top for use by the technician and all the electronic equipment securely rack mounted. The electronic equipment consists of two 400 channel pulse height analyzers, two-channel and four-channel auxiliary amplifiers, a digital magnetic tape recorder, a punched paper tape recorder, a parallel to series converter, a power supply and a line voltage regulator. The remaining rack space is used for storage and a circuit connection panel. The shadow shield counter itself is permanently fixed to the floor of the trailer over the rear axles.

SHADOW SHIELD WHOLE BODY COUNTER



1260779

MOBILE WHOLE BODY COUNTER SHADOW SHIELD

The Mobile Whole Body Counter Shadow Shield Detector is based on the design by Roesch and Palmer and incorporates an 11-1/2 inch by 4-inch NaI crystal having seven 3-inch photomultiplier tubes. The subject lies on a cushioned sled which is gear driven under the crystal by an electric motor. Microswitches at either end of the counter base automatically stop the sled when it has traversed the length of the counter. Shielding is provided by lead bricks. The shielding system has been optimized to achieve a maximum of shielding with a minimum of weight. An ambient gamma ray must penetrate a minimum of slightly more than 2 inches of lead to strike the crystal. The crystal with its shield rests on a 2-inch iron plate over the center of the counter and four inches of lead surround the crystal on top and sides. The combined weight of the shield is approximately 2200 pounds. The entire shadow shield counter weighs approximately 6 tons. The normal counting time is 10 minutes per examination and may be changed by changing gears on the motor-drive mechanism. The detection levels for most gamma-emitting nuclides are the same as for the stationary unit. All of the detectors that are used in the stationary Whole Body Counter are also available for use in the mobile unit.

1260781

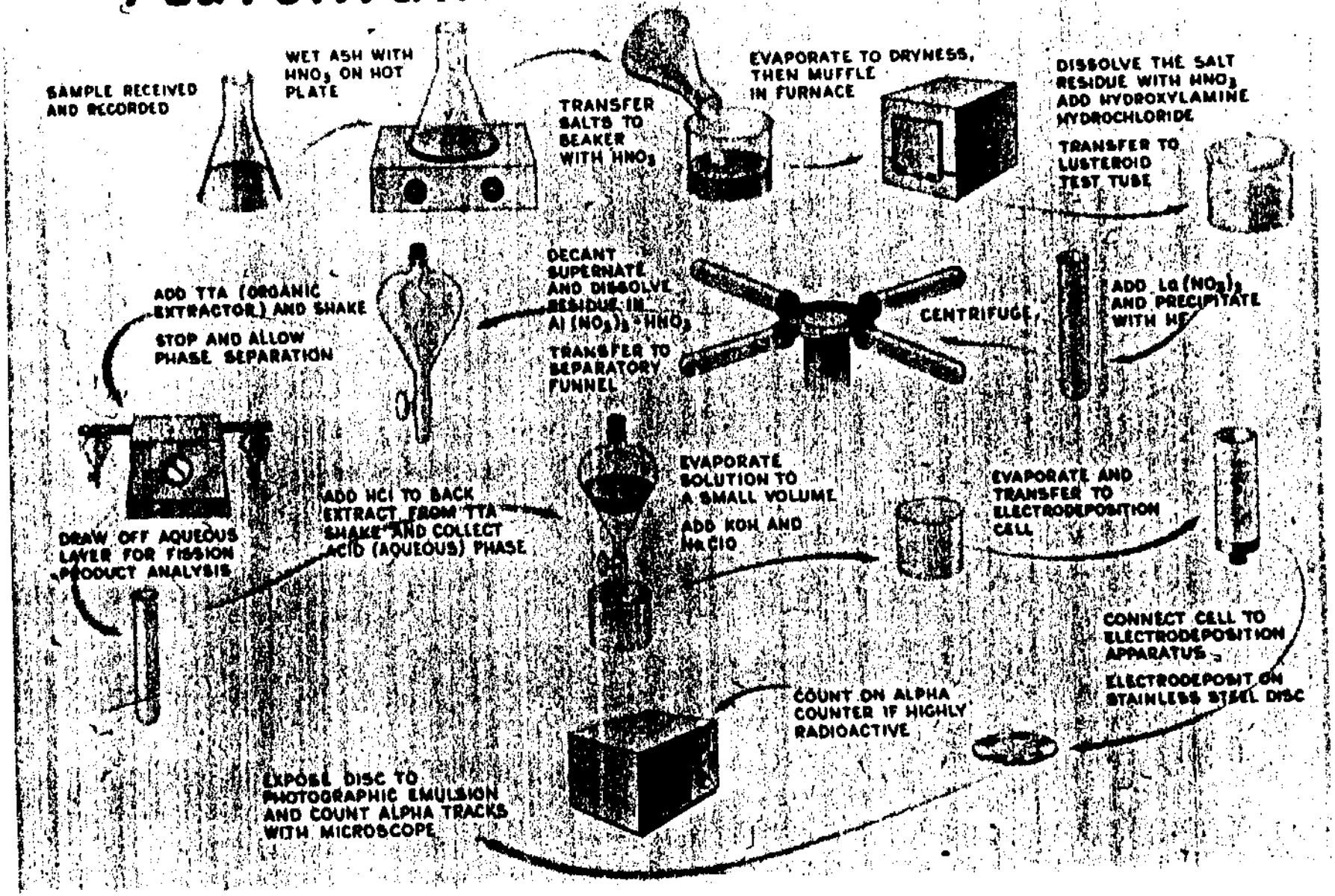
747 BUILDING EXTERIOR

This facility houses the Radiation Protection Operation's bioassay laboratory.

The laboratory conducts a large-scale plutonium urinalysis program for Hanford Personnel. Last year approximately 6000 routine and special plutonium urinalysis samples were processed by the laboratory in maintaining surveilance and evaluation of plutonium deposition in Hanford employees. In addition, the laboratory conducts routine urinalysis programs for both uranium and tritium. Special analytical programs have also been established for evaluating depositions of several other radionuclides, including promethium 147, strontium 90, and, americium 241. Special evaluations for plutonium are also performed on a wide variety of biological specimens, including feces, autopsy samples and animal experiments.

HANFORD EXPOSURE EVALUATION

PLUTONIUM BIOASSAY PROCEDURE



FLOW CHART OF PLUTONIUM BIOASSAY PROCEDURE

The plutonium bioassay program is the main routine analytical procedure carried on by the bioassay laboratory. This flow chart indicates the major steps involved in separation and quantitative determination of plutonium excreted in urine. The complexity of the processing required is evident from the chart. This process has a detection limit of 0.05 d/m. Also, the laboratory has a one-shift capability of processing up to 280 personnel samples per week. Samples processed by this procedure require about two weeks for completion.

A rapid analysis system, requiring less than one day, is used to confirm suspected higher-level samples resulting from deposition incidents.

EVAPORATION HOODS AND MUFFLE FURNACES

The first step in plutonium urinalysis is to break down the organic salts into inorganic nitrite salt residue by wet ashing with nitric acid. After wet ashing, the specimens are evaporated to dryness in the hoods that are pictured on the left side of the slide. The residue is then muffled at 575°C for one hour to destroy the residual organic material.

1260787

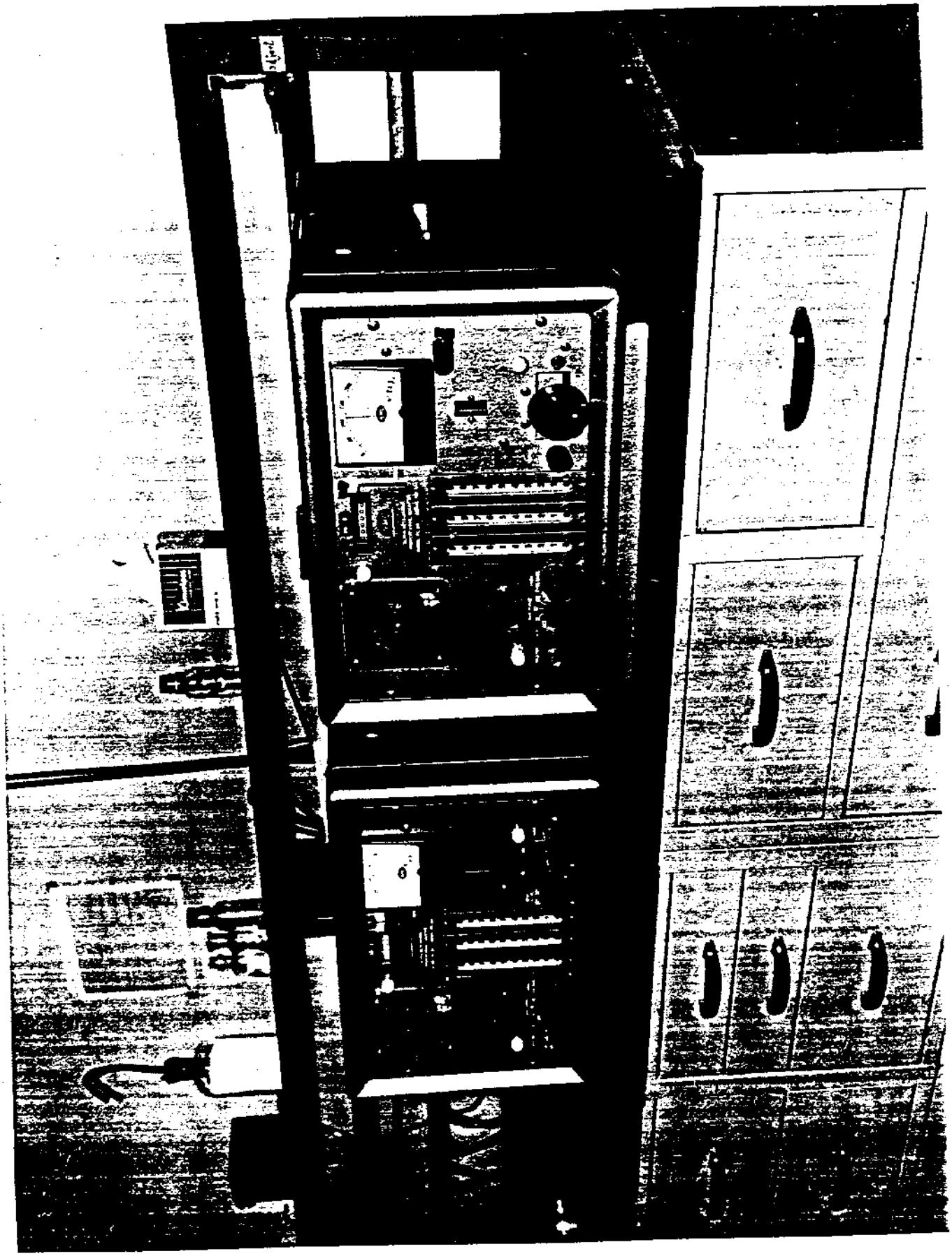
ELECTRODEPOSITION APPARATUS

This apparatus, in effect a bank of miniature electroplating cells, is used to electrodeposit plutonium on a small stainless steel sample disc. Samples are electrodeposited by this apparatus for five hours. Between 90 and 98 percent of the plutonium contained in the original sample is recovered.

1260789

MICROSCOPY

Glass microscope slides coated with NTA emulsion are exposed for one week in contact with the stainless steel discs upon which the plutonium electrodeposition has been made. Alpha particles emitted from the plutonium produce "tracks" in the NTA emulsion. These exposed slides are developed in a manner similar to photographic film and are then examined under the microscopes pictured in the slide. The alpha particle tracks are counted over a predetermined area of the emulsion. Blank urine samples that are spiked with known concentrations of plutonium are processed along with the routine field samples. These calibrations are used to relate the track density to the disintegrations per minute of plutonium present in the sample.

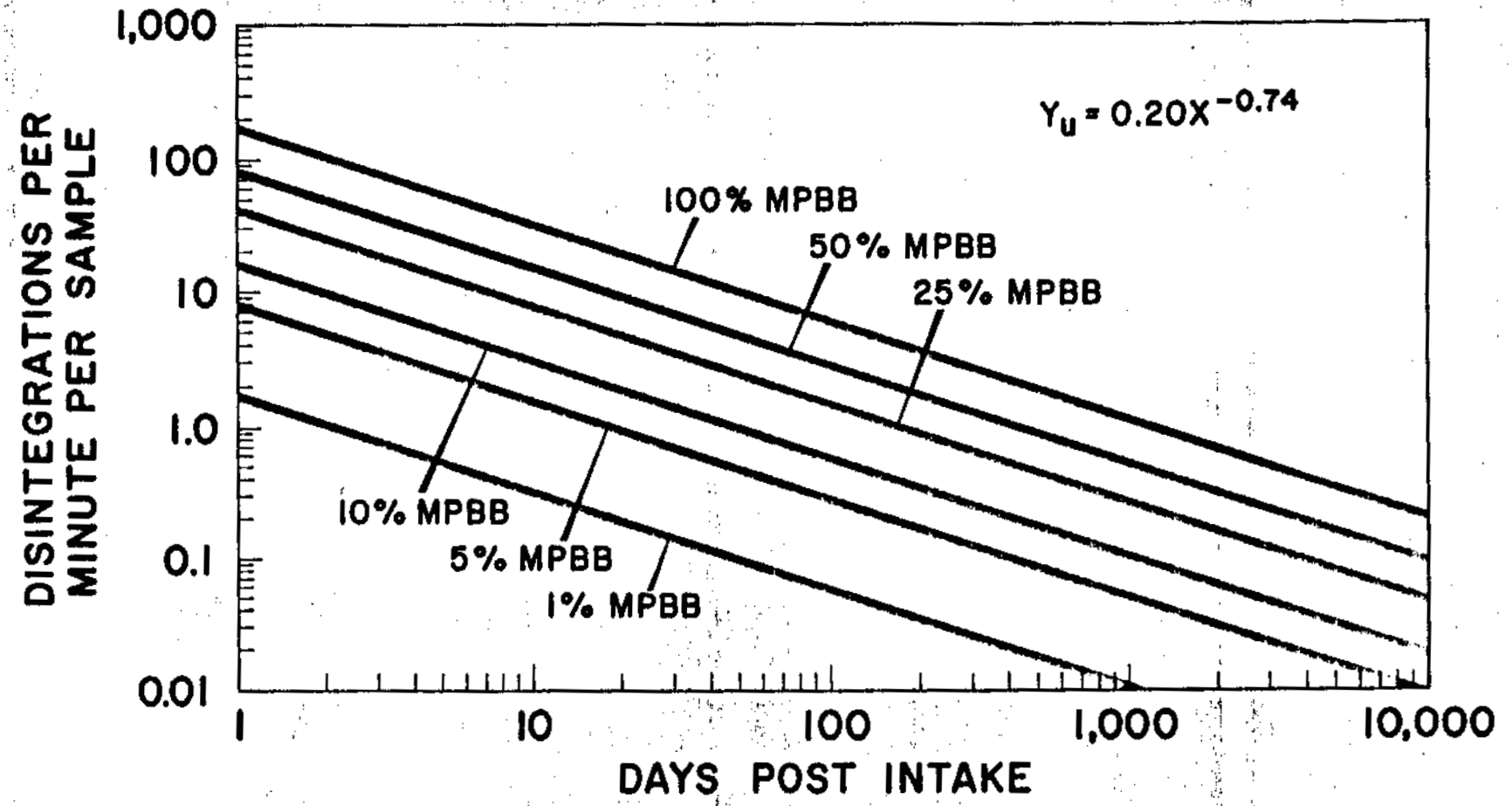


1260791

PROPORTIONAL COUNTERS

When rapid analysis is required for suspected plutonium deposition cases, the samples are counted on these low background proportional counters. These instruments are also used whenever plutonium samples are processed which may have sufficient activity to present a potential contamination problem in the darkroom process. Additionally, they are used for evaluation of bioassay samples being analyzed for strontium 90 or promethium 147.

THEORETICAL PLUTONIUM URINARY EXCRETION RATES RESULTING FROM INTERNAL DEPOSITION OF SOLUBLE PLUTONIUM



1260793

THEORETICAL Pu URINARY EXCRETION CURVES

In the evaluation of plutonium urinary excretion data to determine the amount of soluble plutonium internally deposited in a person, a mathematical model developed by Langham is often applied in cases in which the excretion data indicate the deposited plutonium was readily solubilized by the body fluids. The accompanying slide illustrates graphical applications of this model, which is expressed mathematically as $Y_u = 0.20x^{-0.74}$

where x = number of days elapsed between deposition and sample collection

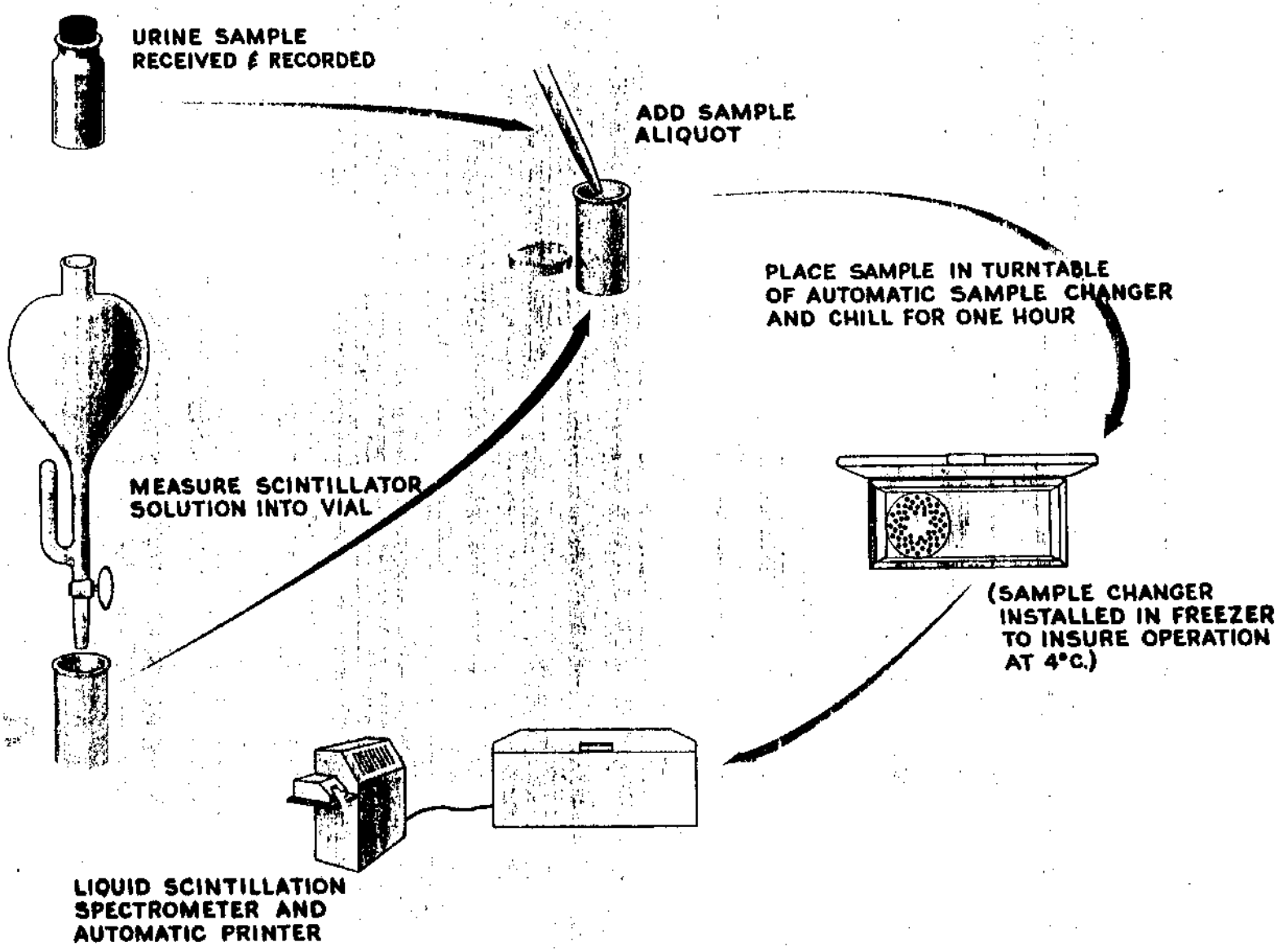
and Y_u = daily urinary excretion rate of readily soluble plutonium, expressed as a percent of the initial deposition of readily-soluble plutonium

The equation is plotted for assumed internal depositions of readily-soluble plutonium equal to 1%, 5%, 10%, 25%, 50% and 100% of the maximum permissible body burden (MPBB) (0.04 μc) considering bone to be the critical organ of reference. Thus, in cases where Langham's model is applicable, a urinary excretion rate of ~ 1.7 d/m Pu on the first day following deposition indicates an initial deposition of 1% MPBB (4×10^{-4} μc) of readily-soluble plutonium, a urinary excretion rate of 17 d/m on the first day following deposition indicates an initial deposition of 10% MPBB, and so forth.

It is also of interest to relate this slide to our capability to detect various amounts of internally deposited readily-soluble plutonium from urinalysis of samples collected at different times after occurrence of the deposition. Our current analytical and counting procedures enable us to detect as little as 0.05 d/m plutonium present in a urine sample. Thus, an internal deposition of readily soluble plutonium equivalent to 1% MPBB can

be detected in samples collected within - 120 days of the date of deposition, a deposition equivalent to 5% MPBB can be detected in samples collected within - 1000 days of the date of deposition, and a deposition of 25% MPBB or greater can be detected from samples collected 10,000 days or more (27 years or more) after the date of deposition.

TRITIUM BIOASSAY PROCEDURE



0-102-736

1260796

FLOW CHART OF TRITIUM BIOASSAY PROCEDURE

The tritium bioassay program is primarily directed to routine analysis of urine samples collected from employees working at the Plutonium Recycle Test Reactor (PRTR). Tritium is generated in heavy water moderated reactors such as PRTR through the reaction, D^2 (n, γ), T^3. In the case of PRTR, the radiation protection program with respect to this particular radionuclide, takes on added impetus in that all three water systems, (primary coolant, moderator, and reflector) are composed of D_2O.

The flow chart indicates the steps involved and the equipment used in analyzing for this low energy beta emitter (E_m = 0.018 mev). Sample preparation consists of combining the scintillator solution and a ml of urine in a vial. The vial is then placed in a mechanized sample changer which lowers the vial between two photomultiplier tubes that are connected in a coincidence circuit. The photomultipliers are used to convert the light energy emitted by the scintillator to electrical pulses, to provide pulse amplification and to minimize the counting of spurious noise pulses. Pulses from the coincidence circuit are then sorted by the pulse height analyzer. The apparatus is calibrated by placing known concentrations of tritium in the liquid scintillator and determining the count rate. A detection sensitivity of 1 μc of tritium per liter of urine is routinely attained. During 1963, 2750 tritium bioassays were performed using this procedure.

The whole body dose is then determined from the equation:

$$\text{Dose} = 0.5\ C_o\ t \text{ mrem}$$

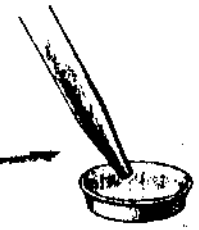
C_o = specific activity (c T/liter)

t = time (days)

This equation assumes a biological half life of 12 days, an average beta energy of 5.7×10^{-3} mev, and an RBE of 1.7.

URANIUM BIOASSAY PROCEDURE

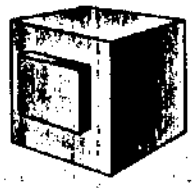
URINE SAMPLE RECEIVED AND RECORDED



ADD ALIQUOT OF SAMPLE AND SPIKE SOLUTION TO PLATINUM DISHES

DRY SAMPLES, SPIKE AND BLANK UNDER HEAT LAMP

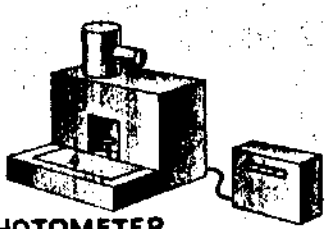
ADD $NaF+Na_2CO_3$ FLUX PELLET TO EACH DISH



FUSE FLUX WITH SAMPLES IN MUFFLE FURNACE

COOL SAMPLE

PLACE SAMPLE IN FLUOROPHOTOMETER AND MEASURE OUTPUT QUANTITATIVELY WITH GALVANOMETER



FLUOROPHOTOMETER

GALVANOMETER

1260798

FLOW CHART OF URANIUM BIOASSAY PROCEDURE

The uranium bioassay program is primarily applied to the routine analysis of uranium in urine samples collected from employees whose work is related to the fabrication of uranium fuel elements. One ml of urine is pipetted onto a small platinum dish and then dried under a heat lamp. A flux pellet containing sodium fluoride and sodium carbonate is added to the dish. The flux is fused with the urine sample by placing the sample for three minutes in a muffle furnace heated to 1000 degrees centigrade. After cooling, the sample is then placed into a fluorophotometer and the fluorescence is read and recorded relative to a uranium standard and a blank. A detection level of about 2 ug U/l is routinely obtained. During 1963, 1800 urine samples were analyzed for uranium content by this procedure.

FILM DOSIMETER PROCESSING

A Pictorial Brief

Hanford policy requires that the quantity of externally received radiation shall be evaluated for each person who enters a Hanford production area, laboratory area or radiation zone.

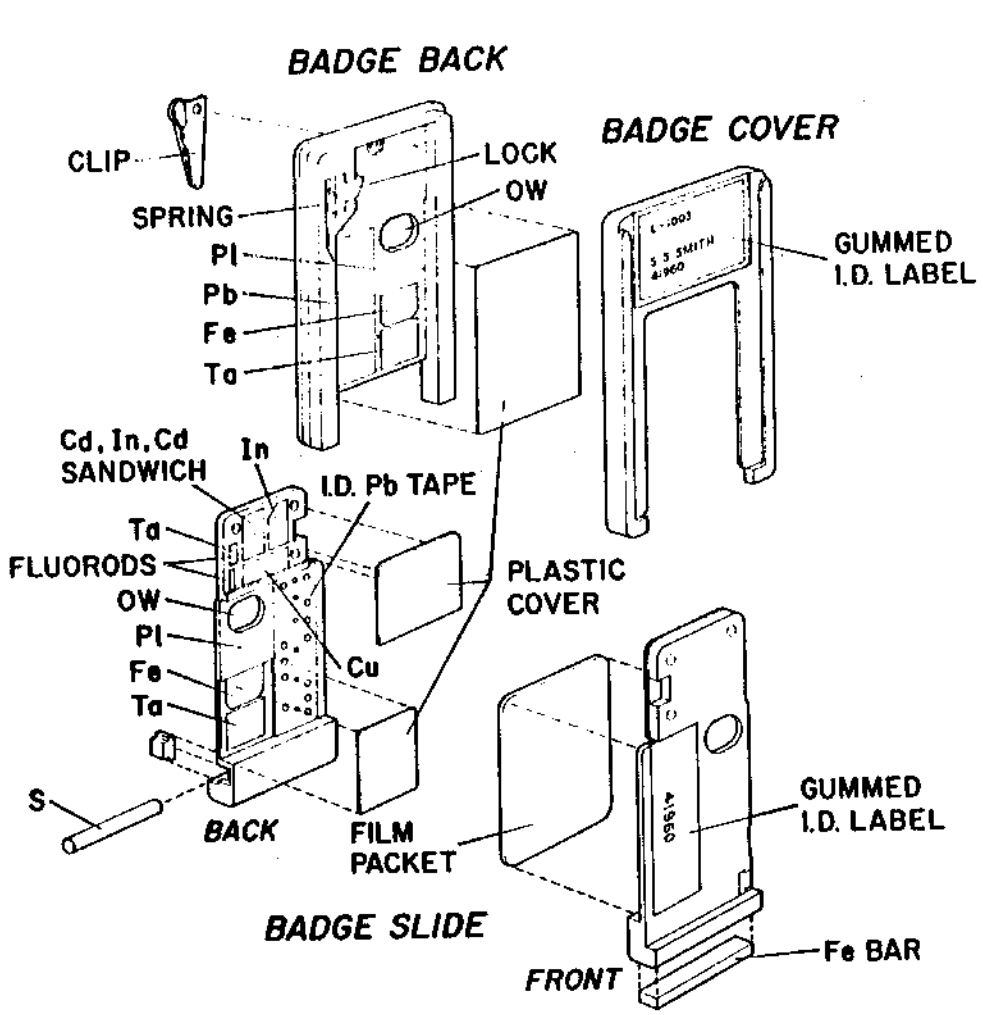
The principal basis for exposure evaluation is the film dosimeter. There are three film dosimeters in current use at Hanford. These are the Beta-Gamma Film Badge Dosimeter, Neutron Film Badge Dosimeter and Film Ring Dosimeter.

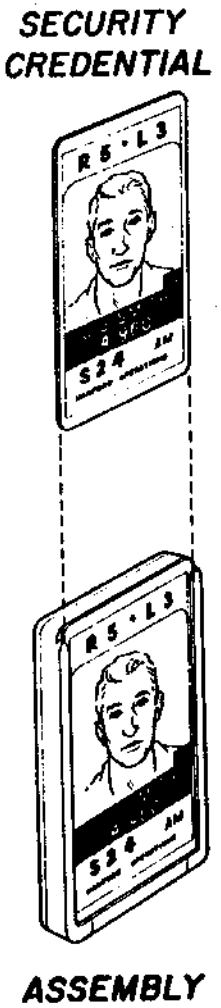
On a monthly-quarterly system about 48,000 beta-gamma film badge dosimeters are processed per year. The processing of each film yields an estimate of the beta, gamma and X-ray exposure received by the individual for the period the dosimeter is worn.

Persons whose annual exposure is expected to be less than 1 rem are on a quarterly dosimeter exchange period and others are on a monthly exchange schedule.

HANFORD EXPOSURE EVALUATION

HANFORD FILM BADGE DOSIMETER





RADIATION PROTECTION OPERATION
AUGUST 10, 1962

HANFORD EXPOSURE EVALUATION

SUMMARY OF HANFORD FILM BADGE DOSIMETER PERFORMANCE

ROUTINE DOSIMETRY

DOSIMETER COMPONENT	TYPE OF RADIATION	RESPONSE ENERGY	DOSE RANGE	MEASUREMENT	CALIBRATION ENERGY
FILM	X-RAY, γ-RAY	0.01 - 0.050 Mev.	0.001 - 15 r	FILM DENSITY	0.017 Mev.
FILM	X-RAY, γ-RAY	0.05 Mev. - UP	0.015 - 1500 r	FILM DENSITY	0.05 - 2 Mev.
FILM	BETA RAD.	0.5 Mev. - UP	0.025 - 2000 rads	FILM DENSITY	URANIUM BETA RADIATION

SERIOUS RADIATION EVENT DOSIMETRY

UNSHIELDED FLUOROD	X-RAY, γ-RAY	0.02 - 0.05 Mev.	5 - 1000 r	FLUORESCENCE	0.03 Mev.
TANTALUM SHIELDED FLUOROD	X-RAY, γ-RAY	0.05 Mev. - UP	10 - 10,000 r	FLUORESCENCE	0.05 - 2 Mev.
INDIUM	NEUTRON	0.025 - 0.3 ev	1 - > 2000 rads	In^{116} DECAY	0.025 ev
CADMIUM - INDIUM - CADMIUM	NEUTRON	0.3 - 2 ev	1 - > 2000 rads	In^{116} DECAY	0.3 - 2 ev
COPPER	NEUTRON	2 ev - 1 Mev.	1 - > 2000 rads	Cu^{64} DECAY	0.05 - 1 Mev.
CADMIUM - INDIUM - CADMIUM	NEUTRON	1 - 2.9 Mev.	1 - > 2000 rads	In^{115} DECAY	1 - 2.9 Mev.
SULFUR	NEUTRON	2.9 Mev. - UP	1 - > 2000 rads	P^{32} DECAY	3 - 14 Mev.

When it is determined that a person should routinely be provided a dosimeter, a keypunched card informs the computer master file for exposure of such need. The film dosimeter is sent to the proper point for pick up and worn for the prescribed period. When the time comes for processing the film dosimeter, they are brought in by transportation crew and racked as the first step in processing.

1260805

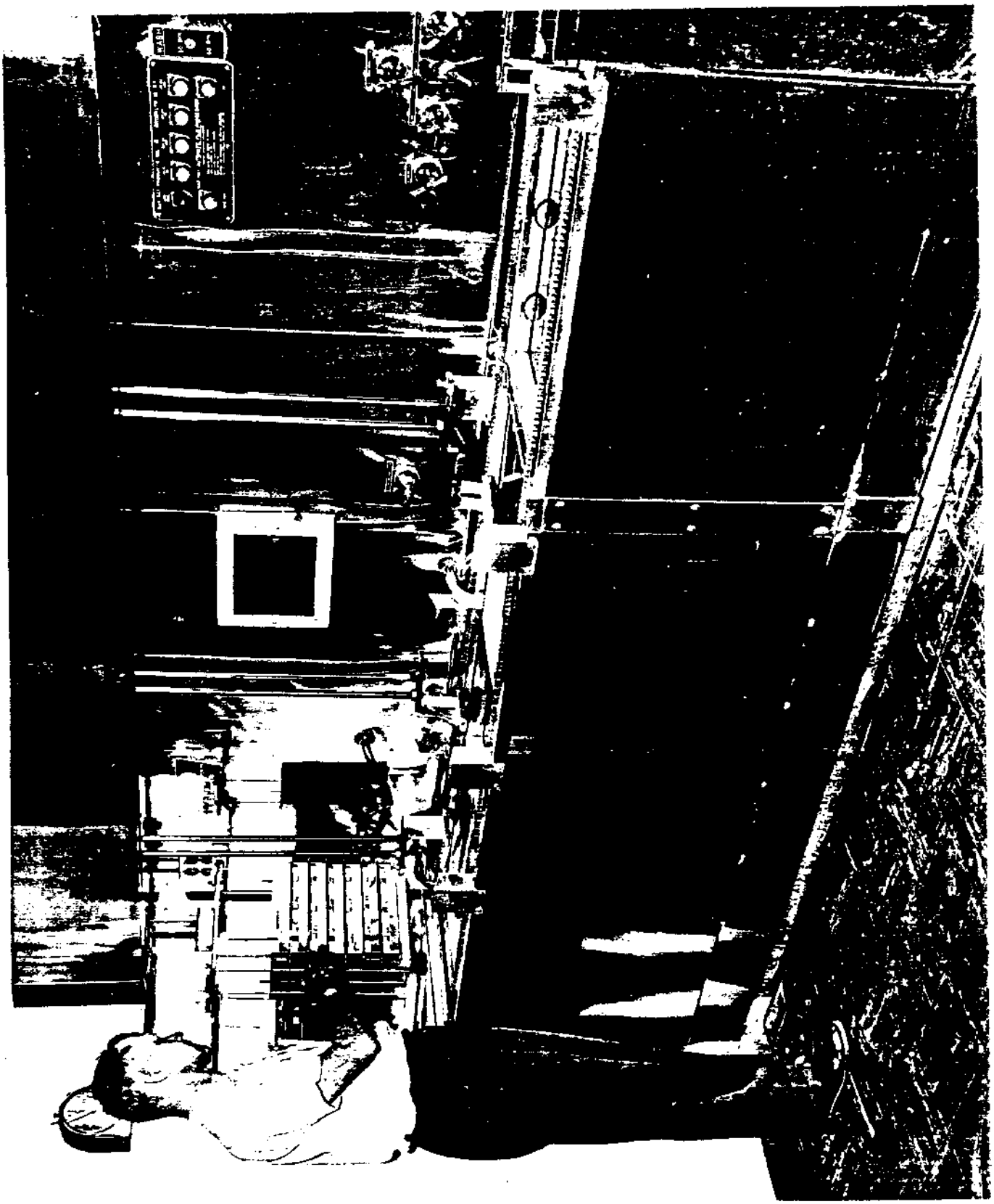
From the racks the trays of dosimeters are taken to the dosimeter processing machine. Here the operator places the dosimeters in a slotted disk which rotates the dosimeter to a position where an identification is X-rayed onto the film and then to a position where the film is removed and new film inserted. The dosimeter is then replaced in the tray in the order in which received and returned to the rack until time for the next exchange.

1260807

The film packets are bundled and taken to the darkroom where the film is placed in slotted plastic trays, one film to each slot. There is both a sensitive (508) and insensitive (1290) film in the Dupont 558 dosimeter packet. The sensitive film is trayed for processing and the insensitive placed in a light tight box until it is verified that there is no need to process it. If needed, as a result of very high exposures, the insensitive film is processed and the film or films are obtained.

When sufficient trays are filled with film, they are placed in a film processing carrier. Eight hundred and fifty films can be processed in one carrier. The carrier is then processed through the various stages of photographic development by a chain driven pneumatic lift system. Time and temperature are automatically controlled throughout the process.

With each batch of personnel film processed a set of calibration film is processed. Each set consists of 14 pieces of film exposed to Ra γ at doses from 15 mR to 10 R, 13 pieces of film exposed to uranium β at doses from 15 mrads to 5 rads, 7 pieces of film exposed to 17 Kev X-rays at doses from 20 mr to 160 mr and 10 pieces of blank film.



1260809

After the processing which takes about one hour and the drying of the film which is usually accomplished overnight, the film, still in the plastic trays, is taken to the automatic densitometer. The automatic densitometer indexes the trays forward one slot at a time. A plunger carries a film to the reading head where the photo-electronics read the film identification and the film darkening behind the open window, plastic, iron and tantalum filters. This reading in the form of electrical impulses is fed to a keypunch machine which records the densitometer reading in punched card language. Certain common information such as batch number, period of measurement, etc. is also automatically punched.

1260811

After sorting on identification number the cards obtained from the densitometer are compared on a collator with a complete prepared set of cards identifying those persons for whom film dosimeters should be obtained at this processing. Cards for which there is no match indicates an exception in dosimeter accountability.

When accountability of dosimeters is established, the film density cards and calibrated film density cards are sent with transmittal to data processing where the computer determines the various doses, updates the individual records, prepares a number of reports and prepares the master deck for the next processing which completes the cycle.

1260813

Neutron dosimeters are issued at field locations and are identified with the wearer at that time. Approximately 7,000 neutron film badge dosimeters are processed annually. After use the dosimeter is X-rayed to permanently mark the film with location, period of use and identification of the wearer. Thirteen dosimeters are X-ray coded at one time.

After processing, the optical density is read behind the tin and cadmium filters on the slow neutron film (Dupont 558 packet). The difference in the two readings is a measure of the slow neutron exposure.

KODAK
PERSONNEL
NEUTRON
MONITORING
FILM
TYPE A
Neutron
Dosimeter

1260815

126081b

Proton recoil tracks in the thick NTA nuclear track emulsion are counted with the aid of a high power microscope. The fast neutron dose is calculated by comparing the tracks observed with the number of tracks observed on film exposed to plutonium fluoride. The energy spectrum of plutonium fluoride most resembles typical fast neutron spectra observed at Hanford.

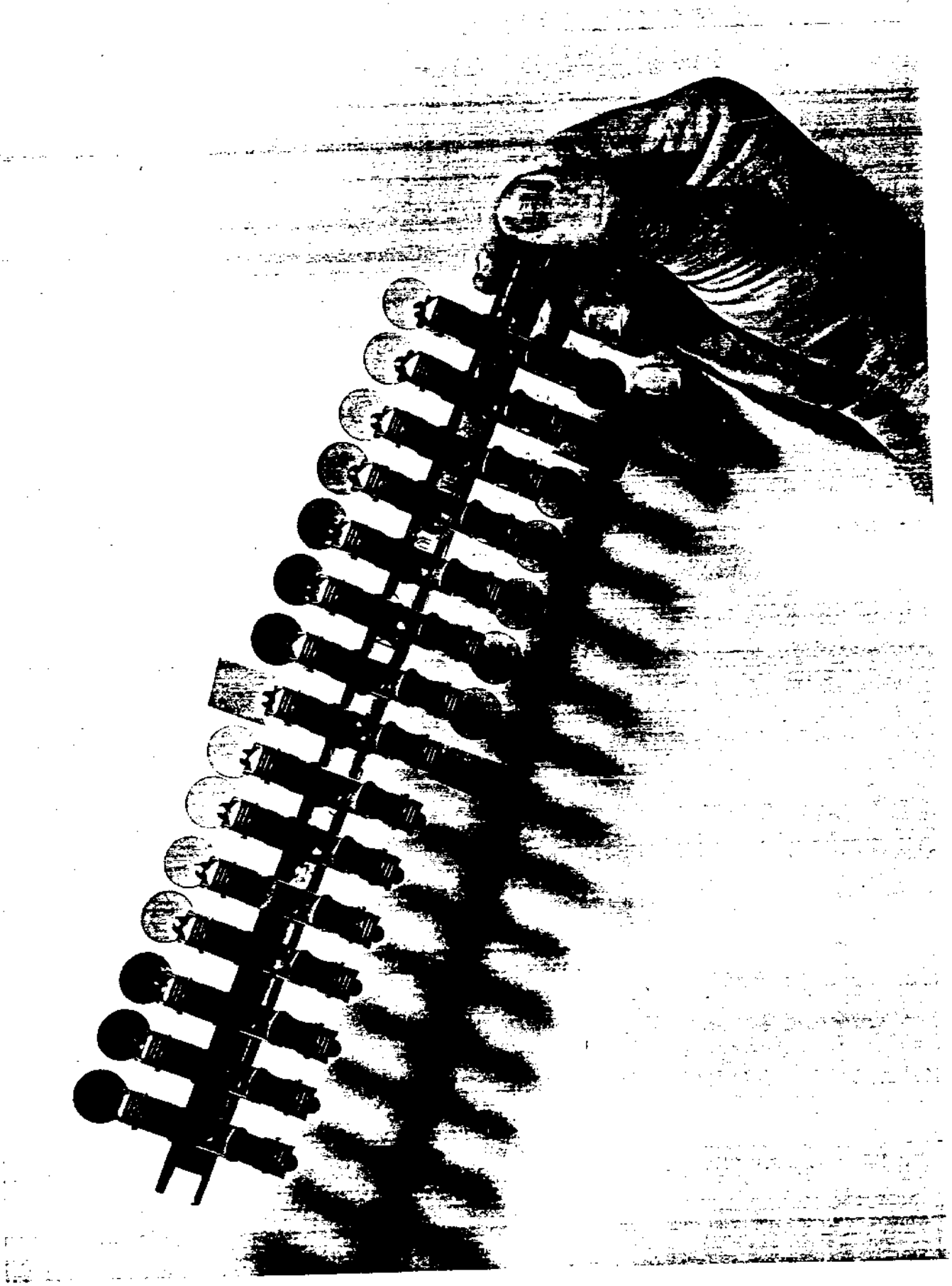
About 4,000 NTA films are read annually.

Hand exposure to ionizing radiation is measured by use of the Hanford Film Ring Dosimeter. The dosimeter is worn while in radiation zones or while working with radioactive materials by employees whose hand exposure is expected to exceed 1 rem per month. About 5,000 Film Ring Dosimeters are processed annually.

0070
3050

Films are removed from finger rings and processed through the darkroom. Accountability is maintained by listing the film on record sheets and maintaining position on the processing hangers.

The film for the ring shown is oblong but in density it will appear much like the older film shown on the hanger.



After darkroom processing the optical density on the finger ring film is read on a manual densitometer. The results are keypunched and processed through a computer for preparation of record and report.

1260824

APPENDIX I

EVALUATION OF AMOUNTS OF INTERNALLY DEPOSITED SOLUBLE PLUTONIUM FROM URINALYSIS DATA

I. "Soluble" Plutonium

The evaluation of the amount of soluble plutonium internally deposited in a person is accomplished by quantitatively analyzing urine samples for plutonium content and fitting the plutonium urinary excretion data thus obtained to mathematical models derived to express the relationships between the amount of soluble plutonium deposited and the resulting plutonium urinary excretion rates to be expected at various lengths of time after deposition. After determining which mathematical model best fits the plutonium urinary excretion data and what values to assign to the parameters in the model, one can then calculate the amount of deposited soluble plutonium which the mathematical model indicates would result in the exhibited excretion rates.

The term "soluble" plutonium refers to that internally deposited plutonium which, at some time during the period of deposition, becomes soluble in the body fluids. For evaluation purposes, it is assumed that essentially all of the solubilized plutonium is subsequently deposited in the bone structure, with a small percentage being excreted at a very slow rate. No mathematical models and no detection or measurement techniques are available to permit the evaluation of that plutonium which might be internally deposited in insoluble form and remain permanently insoluble to the body fluids.

For evaluation purposes, the "soluble" plutonium deposited is considered to consist of "initially soluble" plutonium and/or "initially insoluble" (less readily-soluble) plutonium. "Initially soluble" plutonium is defined as that plutonium which becomes solubilized by the body fluids within a few hours or days after being taken into the body, and hence is present in small amounts in urine samples collected within a few days following intake. "Initially insoluble" plutonium is defined as that plutonium which is not solubilized by the body fluids for several days following intake, but does begin gradually to be solubilized after several days or months have elapsed. In determining whether the soluble plutonium was deposited in initially soluble form, initially insoluble form, or in both forms, the evaluator fits the plutonium urinary excretion data obtained following the deposition to mathematical models describing excretion rates to be expected from depositions of initially soluble and initially insoluble plutonium. The model (models) best fitting the data is (are) then used to calculate an estimate of the amount of soluble plutonium deposited.

II. Langham's Model for Initially Soluble Plutonium

A. Theory

The model used to evaluate the amount of initially soluble plutonium deposited was derived by W. H. Langham.[1] Langham derived the following equation to describe the rate of urinary excretion of initially soluble plutonium entering the bloodstream following an acute exposure, regardless of the mechanism by

which internal deposition occurs: $X = 0.002\ Q_o t^{-0.74}$ (1)
In this equation, "t" is the number of days elapsed between deposition and sample collection, while "X" is the predicted urinary excretion rate of initially soluble plutonium after "t" days, expressed as a fraction of the initial deposition of initially soluble plutonium, Q_o. Solving equation (1) for Q_o yields:

$$Q_o = \frac{X}{0.002\ t^{-0.74}} \qquad (1)'$$

B. Application

Equation (1) indicates that the plutonium urinary excretion rate decreases logarithmically as the number of days between deposition and sample collection increases. For a given value of Q_o, measured in d/m, equation (1) can be expressed graphically as a straight line with slope of -0.74 when paired values of t and X are plotted logarithmically (with "d/m excreted per day" as the ordinate and "number of days elapsed" as the abscissa). Hence, if one plots analytical plutonium urinary excretion data (from a person who received an internal deposition of initially soluble plutonium on a known date) logarithmically versus the number of days between deposition and sample collection, a straight line with slope of -0.74 can be fitted to the plotted data. Furthermore, substituting the X and t coordinates of any point on the "fitted" line for X and t in equation (1)' will yield the estimate of Q_o provided by this application of equation (1). In practice, values of $t = 1$ day and the corresponding value of X are substituted into equation (1)', since when $t = 1$ day the equation reduces to the simple form $Q_o = \frac{X}{0.002}$. Figure (1) presents an example to illustrate the use of Langham's model for initially soluble plutonium.

III. Healy's Model for Initially Insoluble Plutonium

A. Theory

The model used to evaluate the amount of initially insoluble plutonium deposited was derived by J. W. Healy.(2) Healy derived the following equation to describe the rate of urinary excretion of initially insoluble in the lung or other metabolic pool " . . isolated from the normal metabolism of the body but continually injecting plutonium into the bloodstream at a rate dependent upon the character of the deposited material and relevant physiological processes.":

$$E_\mu = 0.002\ \lambda_s Q_o \int_o^R e^{-\lambda t}\ (R-t)^{-0.74}\ dt \qquad (2)$$

In this equation, E_μ = the daily urinary excretion rate of initially insoluble plutonium, expressed as a fraction of the initial deposition of initially insoluble plutonium;

λ_s = the rate of solubilization and transfer to the bloodstream of initially insoluble plutonium;

Q_o = the quantity of initially insoluble plutonium deposited in the body (and retained in the body following the initial clearance from the lung by ciliary action, in the case of deposition by inhalation);

$\lambda = \lambda_s + \lambda_c$ = the total rate of transfer of initially insoluble plutonium from the lung or other metabolic pool, due to solubilization and transfer to the bloodstream (and ciliary action following initial ciliary clearance in the case of deposition by inhalation);

R = the number of days elapsed between deposition of the plutonium in the metabolic pool and the date of urine sample collection;

and t = the number of days required for initially insoluble plutonium to be transferred from the lung or other metabolic pool to the bloodstream.

Although equation (2) is not integrable, the integral has been solved for several values of λ, R, and t by expansion of the exponential term. The "λ curves" thus obtained are used in solving equation (2) for the quantity of initially insoluble plutonium, Q_o, deposited in the body. Healy demonstrated that λ_c, the rate of transfer of initially insoluble plutonium from the lung via ciliary action (not including initial ciliary clearance), is on the order of ten percent of λ. Thus, λ_s can be assumed equivalent to λ for all practical purposes. Of course in cases where the matabolic pool is not the lung but some other site, such as a puncture wound, λ_c is inapplicable and λ_s is thus exactly equivalent to λ. Substituting λ for λ_s and solving equation (2) for Q_o yields:

$$Q_o = \frac{E_\mu}{0.002\,\lambda \int_o^R e^{-\lambda t}\,(R-t)^{-0.74}\,dt} \qquad (2)'$$

B. Application

Several "λ curves" have been prepared to permit one to solve equation (2)' for Q_o. For each λ curve, λ was arbitrarily assigned some given value. Then values of the integral were determined corresponding to the value assigned to λ and the several values assigned to R, the number of days elapsed between deposition in the metabolic pool and subsequent excretion in the urine. The values of the integral have no units, but express the relative excretion rates predicted by the integral at various times after deposition, for the value of λ assumed. Thus, plotting logarithmically the values of the integral versus the corresponding values of R yields a λ curve, for the value of λ assumed, which represents the shape of the excretion curve predicted by equation (2)' regardless of the magnitude of Q_o.

The appropriate value of λ to use in evaluating the amount of initially insoluble plutonium deposited is thus determined by plotting the plutonium urinary excretion data logarithmically ("d/m Pu per urine sample" as the ordinate versus "number of days between deposition and sample collection" as the abscissa) and experimentally determining which λ curve best fits the plotted data.

Equation (2)' can then be solved for Q_o by substituting for E_μ and the integral a pair of values corresponding to any given number of days post intake. In practice it is convenient to choose the maximum value of the integral and the corresponding maximum value of E_μ, the maximum excretion rate (expressed in units of d/m per sample) as determined by the λ curve fitted to the plotted analytical data. Figure (2) presents an example to illustrate the use of Healy's model for initially insoluble plutonium.

IV. Miscellaneous Considerations

Comments on several points are warranted to assist one in understanding the techniques, procedures and assumptions utilized in evaluating the amount of soluble plutonium deposited in a person.

A. Detection Levels

The analytical detection level for plutonium urinalysis has changed over the years as improved analytical and counting procedures were developed. The following table indicates these changes. In order for an analytical result to be considered "positive" it must be equal to or greater than the detection level in effect at the time of analysis.

Time Period	Detection Limit (d/m Pu Per Sample)
Prior to June 1949	0.66
June 1949 to Dec. 1952	0.33
Dec. 1952 to 1/28/53	0.18
1/28/53 to 3/27/53	0.15
3/27/53 to 11/7/53	0.05
11/7/53 to 12/4/53	0.07
12/4/53 to present	0.05

B. Interpreting Plutonium Urinalysis Data

Currently, a person is not confirmed as a plutonium deposition case unless valid positive plutonium urinalysis results have been obtained from at least two samples collected from the person. Preferably a minimum of five samples are currently obtained, with the engineer using his discretion during evaluation should both positive and negative results be obtained.

C. Sample Collection Period

The models for evaluation of initially soluble and initially insoluble plutonium both involve the daily urinary excretion rate of plutonium; that is, the amounts of plutonium excreted in the urine during 24-hour periods. Hence, the urine samples analyzed must be representative of such plutonium excretion. In some cases persons to be sampled are instructed to collect all urine voided during a 24-hour period. However, in most cases the person is requested to collect a "simulated 24-hour urine sample" (sometimes referred to as a "48-hour urine sample"). Such a sample is to consist of all urine voided one-half hour before

ANALYTICAL DATA

d/m Pu per Sample	0.48	0.32	0.19	0.12	0.10	0.060	0.065	0.040	0.035
Days Post Intake	2	4	7	13	20	30	40	50	60

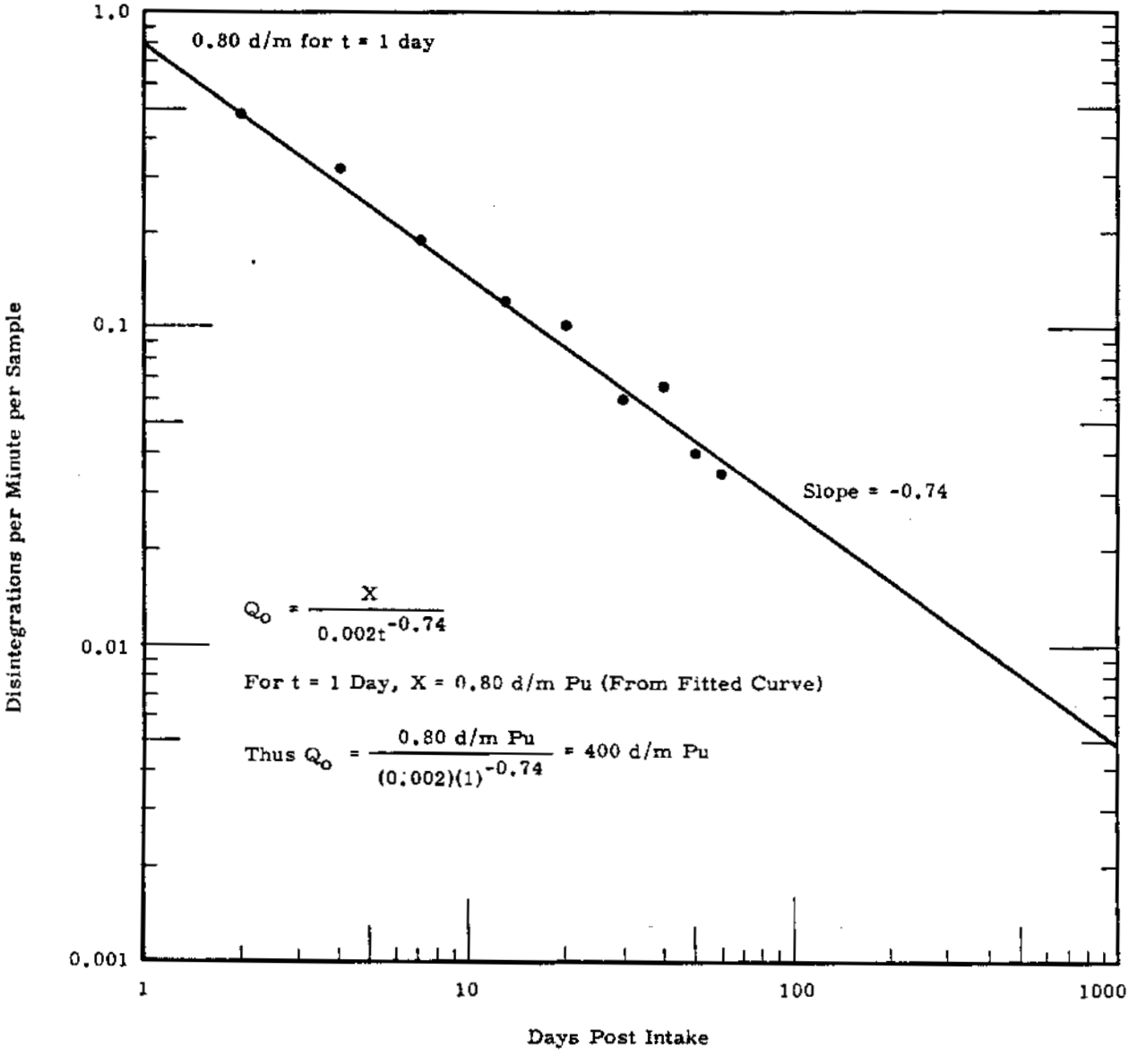


FIGURE 1

Example of Application of Langham's Model for Urinary Excretion of Initially Soluble Plutonium

ANALYTICAL DATA

d/m Pu per Sample	0.27	0.28	0.29	0.34	0.35	0.35	0.37	0.40	0.37	0.38	0.42	0.38	0.40	0.36	0.33	0.33	0.30	0.27	0.21	0.18	0.15	0.13
Days Post Intake	20	30	40	50	70	90	100	150	190	250	300	350	480	600	800	1000	1200	1500	1800	2000	2600	3300

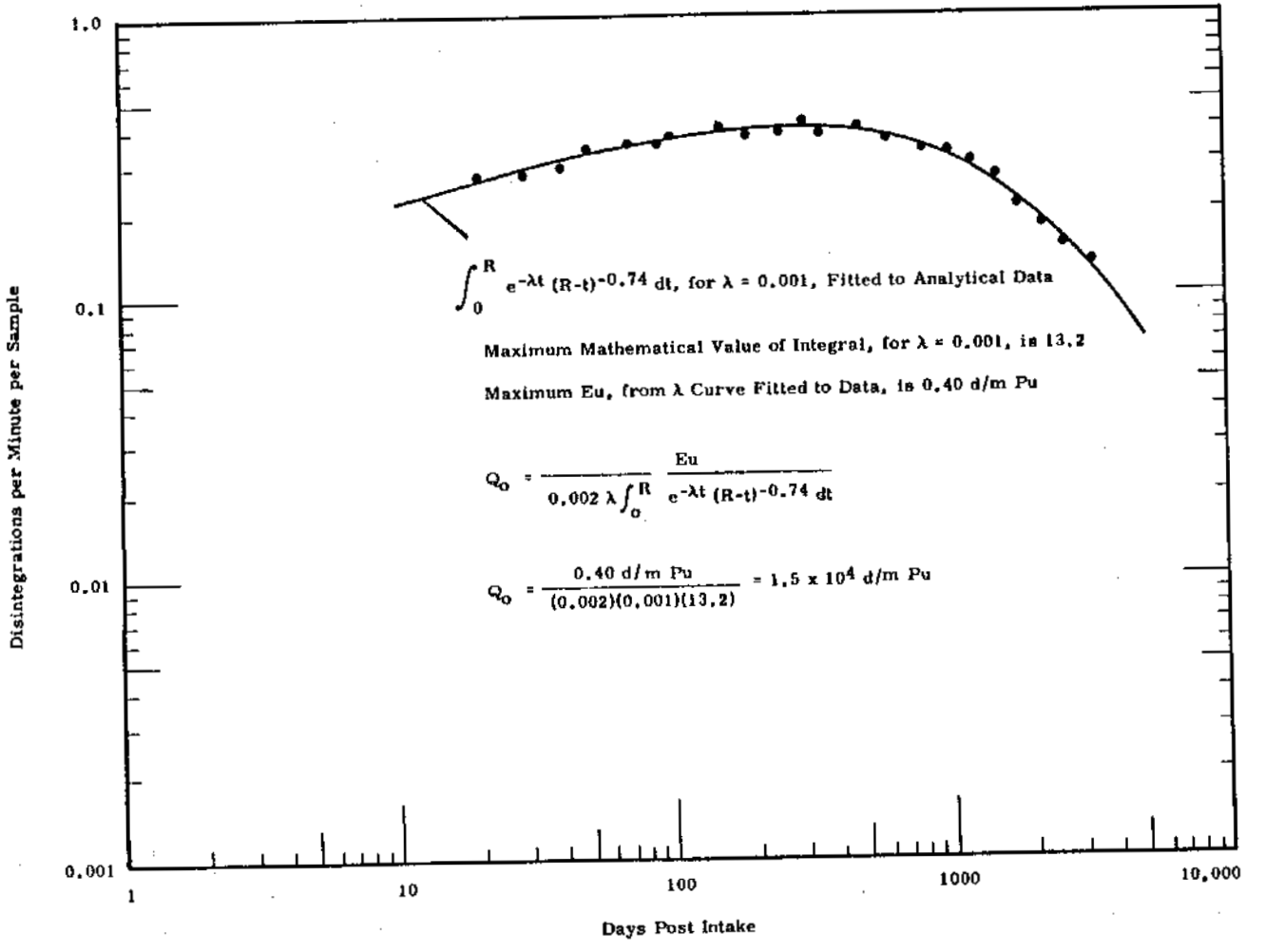


FIGURE 2

Example of Application of Healy's Model for Urinary Excretion of Initially Insoluble Plutonium

HANFORD WHOLE BODY COUNTER

Routine:_____ Other:_____ Date:_____

Name:_____ Payroll No.:_____
Soc.Sec.No.:_____

Age:_____ Weight:_____ Height:_____ Sex:_____

Residence:_____

Amount of Milk/Day:_____ Amount of Meat/Day:_____
(Average, Below or Above Average, None)

Job Title:_____ Bldg. and Area:_____

Exposed to Contamination:_____ Type:_____

Exposed to Neutrons: (yes)_____ (no)_____ (occas.)_____

Date of Incident:_____ Place of Incident:_____

Incident:_____

Counting Time:_____ Energy Calibration:_____ Crystal:_____ HV:_____

Na counts:_____ K counts:_____ Zn counts:_____ Cs counts:_____ GOK counts:_____
(channels 127-142) (channels 68-78) (channels 52-60) (channels 30-36) (channels 10-20)

N_{Na}	N_K	N_{Zn}	N_{Cs}	N_{GOK}
x 7.69×10^{-6}	$- 1.05\ N_{Na}$	$- .403\ N_{Na}$	$- .426\ N_{Na}$	$- 2.06\ N_{Na}$
	$(\quad)(.0707)$	$- .249\ N_K$	$- .185\ N_K$	$- .660\ N_K$
		$(\quad)(1.21 \times 10^{-5})$	$- .260\ N_{Zn}$	$- 1.08\ N_{Zn}$
			$(\quad)(5.57 \times 10^{-6})$	$- 1.05\ N_{Cs}$
				$(\quad)(.05)$
uc Na	grams K	uc Zn	uc Cs	c/m GOK

Note: N's are the total counts in 20 minutes.

1260831

Sheet ___ of ___

HANFORD WHOLE BODY COUNTER

PLUTONIUM WOUND EXAMINATION RECORD

Name _____ Payroll # _____ Suffix _____

Home Address _____

Examinee Accompanied By _____

Incident Occurred: Date _____ Time _____

Building & Area In Which Incident Occurred _____

Wound Type: ___ Puncture ___ Abrasion ___ Laceration Other _____

Location of Wound _____

==========

Date _____ Time _____ of Wound Examination

Count Serial Number _____

(a) Source Count _____ Counts per 10 minutes

(b) Wound Count _____ Counts per 10 minutes

(c) Background Count* _____ Counts per 10 minutes

Calculation:

$$\frac{(b-c)}{(a-c)} \times \left[\frac{\text{Standard source activity d/m}}{2.22 \times 10^6 \text{ d/m/uc}}\right] = \text{uc } Pu^{239}$$

uc at wound site _____

==========

Was Industrial Medical notified as a result of this incident?

_____ Yes, Doctor _____ _____ No

==========

Released From Controlled Injury Zone By _____

Whole Body Counter Examination Conducted By _____

* This background count is either a 10 minute count in the empty counting chamber or preferably a 10 minute count of the examinees' uncontaminated bilateral counterpart.

NAME	SOC.SEC.NO.	DATE
ADDRESS	PAYROLL NO. AND SUFFIX	BLDG. / AREA

AGE	HEIGHT	WEIGHT	SEX	RACE	OCCUPATION	EMPLOYED BY

HOW LONG HAVE YOU LIVED IN THE COMMUNITY WHERE YOU NOW RESIDE? _____ YRS.

WHAT IS THE SOURCE OF DRINKING WATER IN YOUR HOME?

☐ WELL ☐ MUNICIPAL SYSTEM ☐ OTHER (DESCRIBE) _____

HOW MANY GLASSES OF WATER DO YOU DRINK PER DAY?	HOW MANY CUPS OF COFFEE AND/OR TEA DO YOU DRINK PER DAY?	HOW MANY GLASSES OF MILK DO YOU DRINK PER DAY?

WHAT IS THE SOURCE OF YOUR MILK SUPPLY?

☐ COMMERCIAL ☐ LOCAL FARMS (LOCATED WHERE?

☐ OWN COWS _____

WHICH BRAND OF COMMERCIAL MILK DO YOU REGULARLY USE?

HOW MANY TIMES A WEEK DO YOU EAT FRESH MEAT? _____

WHERE DO YOU OBTAIN YOUR MEAT?

☐ MEAT MARKET ☐ LOCAL FARMS (LOCATED WHERE)

☐ HOME GROWN _____

HOW MANY TIMES A YEAR DO YOU EAT THE FOLLOWING SEAFOODS?

FRESH OYSTERS	FRESH CRAB
CANNED OYSTERS	LOBSTER
CANNED CLAM CHOWDER	SHRIMP
CANNED OYSTER STEW	FRESH CLAMS

WHEN WAS THE LAST TIME YOU ATE SEAFOOD AS THE PRINCIPAL PART OF A MEAL?

WHICH SEAFOOD WAS IT?

WHERE DO YOU REGULARLY OBTAIN YOUR FRESH FRUITS AND VEGETABLES?

☐ GROCERY ☐ LOCAL FARMS (LOCATED WHERE?)

☐ HOME GROWN _____

HOW MANY TIMES A YEAR DO YOU EAT THE FOLLOWING GAME BIRDS?

DUCK	QUAIL	CHUKKAR
GOOSE	PHEASANT	GROUSE

HOW MANY TIMES A YEAR DO YOU EAT ANY OF THE FOLLOWING FISH CAUGHT AT THE SPECIFIED LOCATIONS?

FISH	COLUMBIA RIVER: RINGOLD TO RICHLAND	COLUMBIA RIVER: RICHLAND TO MCNARY	YAKIMA RIVER MOUTH TO HORN DAM	CATCH LOCATION UNKNOWN
SALMON				
STEELHEAD				
WHITEFISH				
BASS				
CRAPPIE				
CATFISH				
SUCKERS				
PERCH				
TROUT				
STURGEON				
OTHER				
KIND UNKNOWN				

WHAT FRACTION (¼, ½, ¾, ALL) OF THESE FISH WERE EATEN –

FRESH _____

CANNED _____

FROZEN _____

SMOKED _____

HOW MANY MONTHS ON THE AVERAGE WERE THE FISH PRESERVED BEFORE EATING?

BD–7800–11 0 (2–62) ARC-HE RICHLAND, WASH.

HANFORD'S ENVIRONMENTAL MONITORING PROGRAM

LECTURE OUTLINE

March, 1964

By J. K. Soldat

I. ORGANIZATION AND FUNCTIONS OF ES&EO

A. Purpose

1. Detect, measure, and follow trends of environmental contamination

2. Evaluate and report findings in terms of radiation doses to people in the environs of Hanford

3. Perform R&D on the effects of Hanford on the environs including the Columbia River

B. Organization of Environmental Studies & Evaluation Operation (See chart P. 2)

II. SOURCES OF EXPOSURE IN THE ENVIRONS (See Appendices A, B, & C)

III. RADIOACTIVE MATERIALS IN COLUMBIA RIVER WATER

A. Sources

1. Cooling Water from Production Reactors

(a) Main source of river contamination

(b) Fission products from natural uranium and ruptures

(c) Neutron Activation Products from impurities in cooling water and structural materials

(d) Sampled at reactor areas by IPD

(e) Integrated samples by EMO at basin outlets - for long-lived radionuclides

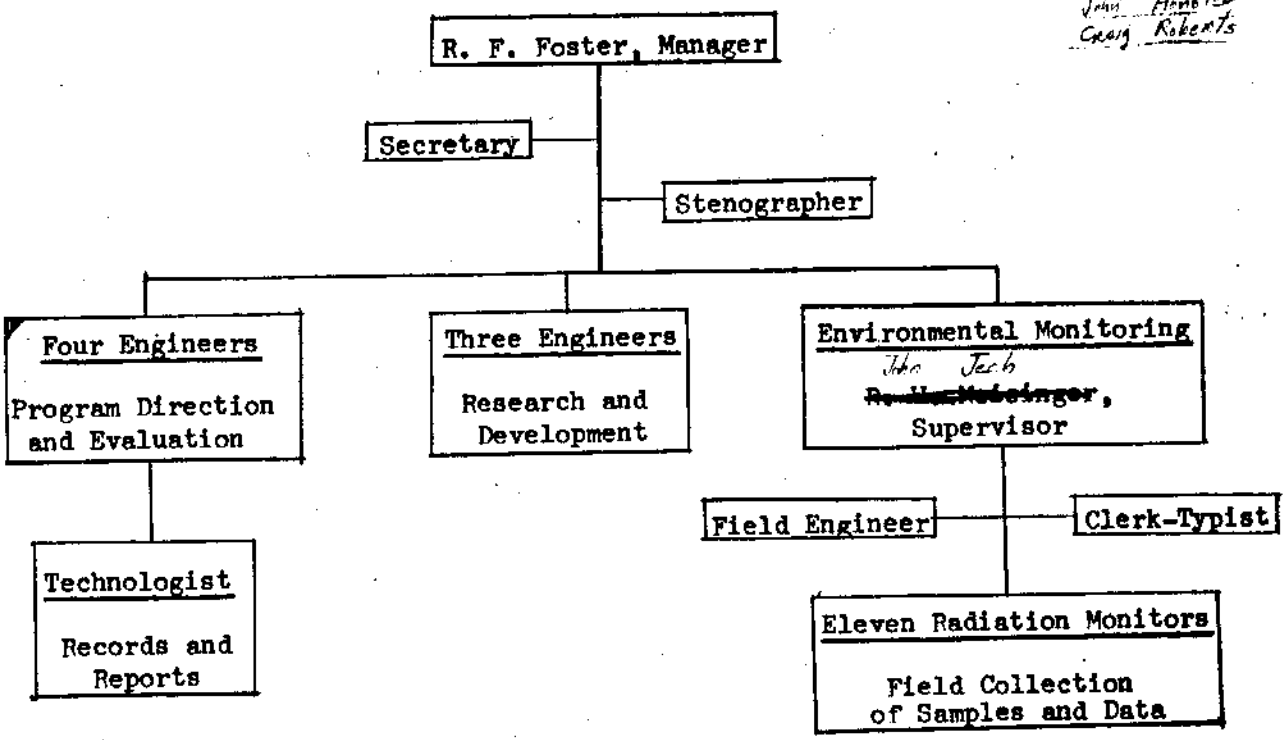
2. 100-N

(a) Recirculating cooling water

(b) Negligible additions to river

ENVIRONMENTAL STUDIES AND EVALUATION

Jack Corley
John Horstad
Craig Roberts



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3. PRTR

   (a) Recirculating cooling water.

   (b) Negligible additions to the river

   (c) Highest activity effluents sampled by operations before release and routed to 340 facility if above limits (5×10^{-5} ucß/cc).

4. 200 Area Liquid Wastes

   (a) To river via ground water in six to seven years

   (b) Negligible amount of H^3 and Ru^{106}.

5. Fallout Materials

   (a) Sr^{90} $\sim 10^{-9}$ uc/cc

   (b) H^3 $\sim 10^{-6}$ uc/cc

B. Exposure Pathways

1. Swimming, skiing, or boating

   (a) Direct external gamma

   (b) Measured by regular pocket dosimeters placed in plastic bottles at 2' to 5' depth.

   (c) Readings - 3. mr/day at 300 Area, 2. mr/day at Pichland, 1.5 mr/day at Pasco-Kennewick.

   (d) Assumed 240 hours of river occupancy per year

2. Drinking Water

   (a) Sampled by EM and analyzed isotopically

   (b) River at Vernita Ferry, Hanford, 300 Area, Pasco, and McNary Dam

   (c) Sanitary at Richland, Pasco, and Kennewick.

   (d) 300 Area Automatic Columbia River monitoring station has continuous measurement and alarm at 300 Area Badge House.

   (e) USPHS sends in samples from Vancouver twice per month

3. Irrigation with Columbia River Water

(a) Irrigation is a negligible source compared with direct deposition of airborne materials.

(b) Beef cattle contain Zn^{65}, but no detectable P^{32} in muscle.

(c) Milk from irrigated dairies contains small amounts of P^{32} and Zn^{65}.

(d) EMO samples milk weekly, beef monthly, and crops in season.

4. Fish and Waterfowl

(a) Fish and ducks pick up P^{32} and Zn^{65} in Columbia River.

(b) Ducks may get some F.P.'s from 200 Area surface ponds.

(c) Main exposure is from P^{32} deposited in bones of people.

(d) Only about 10% of ducks have detectable radioactivity.

(e) Creel census used to define fishing and eating habits.

(f) Few whole body counts of fishermen for Zn^{65} taken - lower than expected.

(g) Experimental test - RF Foster consumed 1 whitefish meal per week and had Zn^{65} uptake four times expected value.

(h) Fish consumption therefore must be overestimated and our calculations of dose received are probably high.

(i) In 1963 average whitefish flesh was ~700 pc P^{32}/gram at Ringold, the area of highest fish content.

5. Oysters

(a) Zn^{65} and some P^{32} persists in Columbia River to the Ocean

(b) Picked up by aquatic organisms especially shellfish

(c) Samples sent to EMO two times per month from oyster beds

(d) Annual average oyster content in 1963 was 80 pc Zn^{65}/gram and 5 pc P^{32}/gram.

IV. RADIOACTIVE MATERIALS IN THE AIR

A. Sources

1. CPD Stacks

(a) Main Hanford contributors to airborne contamination

(b) 0.3 c I^{131}/day, and ~10 mc filterable gross beta per day, some noble gases.

2. Fallout

(a) I^{131} and some Ba^{140}-La^{140} in fresh fallout

(b) Sr^{89}, Zr^{95}-Nb^{95} in intermediate age fallout.

(c) Sr^{90}, Cs^{137} and some Ce^{144}-Pr^{144} in older fallout

3. Reactor Stacks

(a) Noble gases from ruptured fuel

(b) 1-5 curies H^3 per day from PRTR

(c) Some H^3, C^{14}, S^{35} from production reactors

4. Research Facilities

(a) Short-lived F.P. when dissolving irradiated specimens

(b) Long-lived F.P. when studying waste treatment and FP recovery

5. Biology Farm

(a) Radionuclides used in animal tests

(b) Negligible amounts released

6. Stack Monitoring

(a) Major stacks by EMO

(b) Others by RMO or production forces

(c) Limits set for most stacks; important radionuclides will be listed in new RPS.

B. Exposure Pathways

1. Inhalation

(a) Main contribution is I^{131}

(b) Air monitoring is done at "614 Buildings" and transportable "dog houses".

(c) Particle filters, caustic scrubbers (for I^{131}), and recording gamma monitors (high range for emergencies).

(d) Average I^{131} at Tri-Cities in 1963 was $\sim 2 \times 10^{-14}$ uc/cc (1962 was $\sim 8 \times 10^{-14}$ uc/cc due to fallout).

2. Contaminated Crops

(a) Concentrations small - some I^{131} and Sr^{90}.

~~(b) USPHS method of dose estimate~~

(c) ~~Dose from 1 kg crops assumed to be equal to ~25% of dose from 1 liter of milk (good measurements are available on milk).~~ 40% Sr^{90} — Milk
60% Sr^{90} — Other Foods
Pc Sr^{90}/l × 2.5 = Total Sr^{90} pc/day

(d) Dose from I^{131} calculated directly by assuming 60 g/day of leafy vegetables are eaten.

3. Milk

(a) Mainly I^{131} plus some Sr^{90}

(b) Some P^{32} and Zn^{65} when pasture is irrigated with Columbia River water drawn below reactors.

(c) EMO samples 6 farms weekly (milk and pasture grass), 2 milk shed composites each two per month, and 3 commercial brands at store each two per month.

(d) I^{131} in milk was low in early 1963. Peak in June of 84 pc/l due to fallout.

(e) In September 1963 unplanned release of ~80 curies of I^{131} led to measurement of 140 pc I^{131}/liter milk and extrapolated peaks of ~400 pc/liter.

(f) Maximum dose from this release was $\leq$ 30 mrem/thyroid.

(g) Fallout materials in milk were usually below detection levels of 4 pc Sr^{89}/liter and 30 pc Cs^{137}/liter.

4. Beef Thyroids

(a) Sampled at 5 slaughterhouses several times per month.

(b) Analyzed for I^{131} by gamma-scan

(c) Concentrations of I^{131} are 10^2 - 10^3 higher in beef thyroids than in milk and pasture grass, so thyroids are a good trend index when I^{131} in the others is too low to measure.

V. MISCELLANEOUS MEASUREMENTS

A. External Gamma Dose

1. Stray Radiation Chambers

(a) Used near Y-Barricade and at 747 Building (Bioassay Lab)

(b) Average gamma dose is ~0.5 mr/day nearly all due to fallout and natural background radiation.

B. Ground Surveys

1. Control Plots

(a) Small areas of ground (100 ft^2) surveyed repetitively for trend indicator and to detect releases of radioactive materials otherwise missed

(b) Two sets around Purex and Redox stacks and others on Wahluke Slope

(c) Number of radioactive particles plus survey instrument readings recorded monthly to quarterly

2. Burial Ground Audit

(a) Solid waste burial grounds surveyed twice a year to check on contamination status

(b) Status of fences, signs and housekeeping are also audited

3. Aerial Survey

(a) Quarterly flights on project, down river, and over environs

(b) To measure background and check for contamination possibly missed by other measurements

(c) To keep equipment in good working order for use in an emergency

VI. COMPOSITE DOSE (See Annual Reports such as HW-80991 for 1963, for details)

A. Bases for Calculation

1. ICRP parameters for "standard man"

2. Modified for child's thyroid dose to account for difference in organ size and food intake

~~3. USPHS method for fallout in food assumes dose is 25% of that received from fallout in milk on an equal weight basis~~

Adult

Yr.	Max.	
5.5	40 Kg	Fish
99	80 Kg	Meat
36	30 Kg	Leaf Veg
	215 Kg	Other Veg. + Fruit
310	380 l	Milk
440	730 l	Water
17	9 kg	Leaf Veg
365	365 l	Milk

4. Assumed maximum consumptions of specific foods

   (a) 25 lbs of whitefish per year

   (b) 25 lbs of oysters per year

   (c) 60 grams of leafy vegetables per day

   (d) 2.2 liters of water per day (adult only, child varies with age)

B. Exposure Limits for Various Critical Organs

1. GI Tract

   (a) NCRP - 1500 mrems/year

   (b) FRC - 1500 mrems/year

2. Total Body

   (a) NCRP - 500 mrems/year

   (b) FRC - maximum individual, 500 mrems/year

   (c) FRC - average of suitable sample, 170 mrems/year

3. Thyroid

   (a) NCRP - 3000 mrems/year

   (b) FRC - maximum individual, 1500 mrems/year

   (c) FRC - average of suitable sample, 500 mrems/year

   (d) FRC - range concept - annual average intake of 100 pc of I^{131} per day ≙ 500 mrems/year to thyroid of small child.

4. Bone

   (a) NCRP - Maximum Permissible Rate of Intake (MPRI)*

   (b) FRC - maximum individual, 1500 mrems/year

---

* The Maximum Permissible Rate of Intake (MPRI) is taken as the maximum permissible concentration in water for a given radionuclide, as recommended by the NCRP for persons in the neighborhood of controlled area, multiplied by the rate of water intake as defined for the standard man. This amounts to one-tenth of the MPC's for continuous exposure of occupational workers multiplied by 2,200 cc per day, or by 800 liters per year in the case of annual estimates.

(c) FRC - average of suitable sample, 500 mrems/year

(d) FRC - specific nuclides expressed as permissible daily intakes on an annual average basis (Top of Range II).

Sr^{89} - 2000 pc/day
Sr^{90} - 200 pc/day
Ra^{226} - 20 pc/day

C. Composite Doses for the Year of 1963

1. Hypothetical maximum person (adult) consuming local fish, oysters, crops, milk, water, etc.

(a) GI Tract - ~~[illegible]~~ 200 mrems 50%

(b) Total Body - ~~90~~ 83 mrems 25%

(c) Thyroid (adult) - ~~25~~ 19 mrems 5%

(d) Bone - ~~45%~~ 50% of ~~MPRI~~ FRC 10%

2. Pasco Resident (not eating whitefish and not using the river for recreation)

(a) GI Tract - 40 mrems

(b) Total Body - 15 mrems

(c) Thyroid (adult) - 7 mrems

(d) Thyroid (child) - 70 mrems

(e) Bone - 9% of MPRI

3. Richland Residents AVG.

(a) GI Tract - ~~60~~ 25 mrems

(b) Total Body - 15 mrems

(c) Thyroid (adult) - ~~6~~ 8 mrems

(d) [redacted]

(e) Bone - ~~8%~~ 15% MPRI (could be ~15% in 1964, Columbia River water)

4. Rural Resident (consuming local milk and produce, but not whitefish)

(a) GI Tract - 25 mrems

(b) Total Body - 20 mrems

(c) Thyroid (adult) - 6 mrems

(d) Thyroid (child) - 60 mrems

(e) Bone - 15% MPRI

Max Child

Avg Child

Thyroid 115 mrems 8% FRC 30 mrems 5% FRC

APPENDIX A

SOURCES OF RADIATION EXPOSURE IN THE ENVIRONS

I. EXTERNAL

A. Plant Sources

1. Airborne

(a) Gaseous and Particulate

2. Deposited on Vegetation and Ground or in water

3. Water - Liquid Waste Disposal [redacted]

(a) Swimming

(b) Boating

B. Fallout [redacted]

1. Airborne Material

2. Deposited on Vegetation, Ground, or in Water

C. Natural Background Radiation

1. Cosmic Rays

2. Radon, Thoron, and their Decay Products

3. Radioactive Substances in Soil, Rocks, Water, Building Materials, etc.

D. Medical Exposures

1. Diagnostic X-Rays - Chest, GI Tract, etc.

2. Dental X-Rays

3. Treatments for Cancer and Dermatitis

II. INTERNAL

A. Plant Sources

1. Breathing Airborne Materials

(a) Gaseous - I^{131}, Noble Gases

(b) Particulate - F.P.'s., U, and Pu

2. Drinking Water-borne Materials

   (a) Reactor Cooling Water Radioactivity

   (b) Fallout of Airborne Materials

3. Eating Vegetation Contaminated by:

   (a) Water-borne Materials through Irrigation

   (b) Fallout of Airborne Materials onto Vegetation

4. Eating Meat From:

   (a) Grazing Animal fed on irrigated [redacted] vegetation

   (b) Fish caught near the project [redacted]

B. Fallout [redacted]

1. Breathing airborne materials

2. Eating vegetation and meat directly or indirectly contaminated

3. Drinking water containing Fallout [redacted]

C. Natural Background Radiation

1. Radon and Thoron and decay products breathed into lungs

2. Eating foods and drinking water containing naturally radioactive materials

3. Natural H^3, C^{14}, K^{40}, and Ra^{226} in body

D. Medical Treatments

1. Treatments with Isotopes

   (a) I^{131} - Thyroid

   (b) P^{32} - Cancer

2. Radioactive Tracer Tests

   (a) Na^{24} - Blood Circulation Study

APPENDIX B

NATURAL RADIOACTIVE SUBSTANCES

I. EXTERNAL EXPOSURES

A. Cosmic Rays

1. 0.1 mr/day at sea level

2. 0.2 mr/day at 5000 feet above sea level

B. Naturally Occurring Radioactive Materials in:

1. Soil, rocks, air, water, and building materials add up to

2. 0.2 mr/day

C. Total Whole Body Exposure

1. 0.3 mrad/day

2. 3 to 4 rad per 30 years

II. INTERNAL EXPOSURES

A. Lungs

1. Radon and Thoron and their Decay Products, inhaled

2. One (1) to 50 mrem/day

B. Bone

1. Ra^{226} and K^{40} in bone and tissues

2. 0.15 mrem/day

C. Gonads

1. C^{14}, K^{40}, Ra^{226}, and Decay Products of Ra^{226}

2. 0.07 mrem/day

D. Body Concentrations

1. $H^3 - 3 \times 10^{-5}$ uc

2. $C^{14} - 9 \times 10^{-2}$ uc

3. $K^{40} - 1 \times 10^{-2}$ uc

4. $Ra^{226} - 2 \times 10^{-4}$ uc (variable)

III. MISCELLANEOUS DATA

A. Radium Springs

1. World Maximum - 7×10^{-4} uc Ra/cc at Masutomi, Japan
2. U. S. Maximum - 3×10^{-4} uc Ra/cc at Boulder, Colorado
3. Generally - Few above 3×10^{-5} uc Ra/cc

B. Radium in Tap Water

1. U. S. Generally - 0 to 1×10^{-10} uc Ra/cc
2. Joliet, Illinois - 6×10^{-9} uc Ra/cc

C. Radon in Air

1. Normally in room air - 10^{-10} to 10^{-11} uc/cc
2. In Colorado, uranium mines - 10^{-6} to 10^{-5} uc/cc of air
3. Normally in air of Pacific Northwest - 1 to 5×10^{-11} uc/cc

D. Thoron in Air

1. Thoron is normally 0.1 percent to 5 percent of Radon concentrations

E. Uranium

1. In Earth's crust - 10^{15} Tons
2. In oceans - 10^{10} Tons
3. Average in surface soil - 1 to 2 ppm
4. Normally in Columbia, Snake, and Yakima River water - 10^{-9} uc/cc
5. Normally in Benton City well water - 10^{-8} uc/cc

F. Tritium

1. Total in atmosphere - 2/3 ounce
2. Total in oceans - 2 pounds
3. Total in inland waters - 1/3 ounce

APPENDIX C

RADIATION EXPOSURES FROM SOME MEDICAL TREATMENTS AND EXAMINATIONS

Procedure	Exposure
Dental X-Ray	1 to 15 R/film
Chest X-Ray	50 mr/film
Fluorscopy	10 to 20 R/min
Barium Contrast Studies	1 to 2 R/series
G.I. Series	1 to 8 R/series
Pregnancy X-Ray Examinations	20 to 65 R Total
Thymus Treatment	75 to 350 R Total
Acne Treatment	500 to 1000 R Total
Tumor Treatment	3000 to 7000 R Total

50% Medical
40% Nat Bkgd 100 mrem/yr.
2.5 Atomic Plants
2.5 Radium
2.5 Fallout
2.5 T.V. Sets 6 mrem/yr.

APPENDIX D

PROBLEMS

I. RELEASE TO RIVER

A. Problem

Compute the maximum sustained release rate of P^{32} per month from an atomic energy plant into a river using the "water → fish → human" pathway and the following assumptions:

1. Averaging over a 12 month period is permissible
2. The MPC of P^{32} in drinking water for non-occupational workers is 2×10^{-5} uc/cc.
3. A person drinks 2200 cc/day
4. The concentration factor $\frac{\text{uc/g fish}}{\text{uc/cc water}}$ for P^{32} between fish and water is:

Jan.	2,000	May	10,000	Sept.	100,000
Feb.	1,000	June	25,000	Oct.	50,000
Mar.	2,000	July	50,000	Nov.	10,000
Apr.	5,000	Aug.	100,000	Dec.	5,000

5. The flow rate of the river is 80,000 cubic feet per sec.
6. The consumption rate of fish is 200 grams per week but only one fish in ten comes from the contaminated river.

B. Solution

1. Average the 12 concentration factors given in the problem and find the annual average factor to be 30,000 uc P^{32}/g of fish per uc P^{32}/cc of water.
2. Calculate the river flow rate in terms of cc/month

   Flow = $8 \times 10^4 \frac{ft^3}{sec} \times 2.83 \times 10^4$ cc/ft^3 x 30 d/month x $8.64 \times 10^4 \frac{sec}{day}$

   Flow = 5.87×10^{15} cc/month
3. Assume allowable intake in uc P^{32}/day is the product of MPC_w and 2.2×10^3 cc/day.

   2×10^{-5} uc/cc x 2.2×10^3 cc/day = 4.4×10^{-2} uc/day

4. Calculate the average number of grams of fish from contaminated river which are actually eaten per day.

$$\text{Consumption} = \frac{200 \text{ g fish/week}}{7 \text{ days/week}} \times \frac{1 \text{ contaminated fish}}{10 \text{ total fish}}$$

$$= 2.86 \text{ g/day of contaminated fish eaten}$$

5. Calculate the P^{32} content of the river and of the fish if one curie of P^{32} per month were discharged to the river.

$$\text{Water content} = 1 \text{ curie} \times 10^6 \frac{\mu c}{c} \times \frac{1}{5.87 \times 10^{15} \text{ cc/month}}$$

$$= 1.7 \times 10^{-10} \text{ uc/cc water}$$

$$\text{Fish content} = 30{,}000 \times \text{water content}$$

$$= 3 \times 10^4 \times 1.7 \times 10^{-10} = 5.1 \times 10^{-6} \text{ uc/gram fish}$$

6. Calculate total daily P^{32} intake if 1 c/month were released.

$$\text{Intake} = (1.7 \times 10^{-10} \text{ uc/cc} \times 2.2 \times 10^3 \text{ cc/d}) + (5.1 \times 10^{-6} \text{ uc/g} \times 2.86 \text{ g/day})$$

$$= (3.74 \times 10^{-7} \text{ uc/day}) + (1.46 \times 10^{-5} \text{ uc/day})$$

$$\text{Intake} = 1.50 \times 10^{-5} \text{ uc/day}$$

7. Find ratio of MPRI and intake from one curie per month released. This ratio is the permissible release rate.

$$\text{Permissible Release Rate} = \frac{(4.4 \times 10^{-2} \text{ uc/day})}{1.5 \times 10^{-5} \text{ uc/day/c released/month}}$$

Permissible Release	$= 2.9 \times 10^3$ c/month*

* Note: This release limit would be reduced to $\sim 1.5 \times 10^3$ c/month if it were calculated on the basis of the FRC's recommendation of 1.5 mrem/year to the bone of the maximum individual.

II. RELEASE TO ATMOSPHERE

A. Problem

Compute the maximum permissible concentration of I^{131} in the atmosphere outside of an atomic energy plant on the basis of the atmosphere → vegetation → cow → milk → human pathway. Use the following assumptions:

1. The maximum permissible rate of intake is 100 uuc/day
2. Consumption rate for milk is 1 liter/day
3. A cow produces 10 liters of milk/day
4. A cow eats 40 kg of vegetation/day
5. One uc I^{131}/cc of air leads to 10^{+7} uc/g of vegetation
6. 3 percent of the I^{131} eaten by the cow appears in the milk

B. Solution

1. Find intake of cow if air has 1 uc/cc.

   1 uc/cc in air yields 10^7 uc/g vegetation

   so cow eats 10^7 uc/g x 4×10^4 g/day = 4×10^{11} uc/day

2. Find content of milk when 3% goes to milk.

   $$\frac{4 \times 10^{11} \text{ uc/day} \times 0.03}{10 \text{ liters/day}} = 1.2 \times 10^9 \text{ uc/liter}$$

   or milk contains 1.2×10^{15} uuc/liter when air has 1 uc/cc

3. Find ratio of answer in (2) and allowable milk concentration of 100 uuc/liter.

   This ratio is the permissible air concentration

   $$\text{Permissible Concentration} = \frac{100 \text{ uuc/liter}}{1.2 \times 10^{15} \text{ uuc/liter per uc/cc of air}}$$

   $$\boxed{\text{Permissible Concentration} = 8.3 \times 10^{-14} \text{ uc } I^{131}\text{/cc air}}$$

III. STACK SAMPLING

A. Problem

A stack sampler, which had a flow rate of 3 cfm, was operated continuously for one week. The stack discharge rate was 6,000 cfm; the activity released from the stack was Fe^{59}. The net activity (background subtracted) found on the filter paper was 1,000 counts per minute. Assuming the collection efficiency is 85 percent and the counter efficiency is 12 percent, and neglecting the decay of Fe^{59}, calculate the total number of microcuries released to the atmosphere, via the stack, during the week. Calculate the average Fe^{59} concentration (uc/cc) in stack air during the week. (1 cu. ft. = 28,000 cc)

B. Solution

$$\text{Total Activity (uc)} = \frac{1000 \text{ c/m}}{0.12 \frac{\text{c/m}}{\text{d/m}}} \times \frac{1}{2.22 \times 10^6 \frac{\text{d/m}}{\text{uc}}} \times \frac{1}{0.85} \times \frac{6000 \text{ CFM}}{3 \text{ CFM}}$$

$$= 8.84 \text{ uc}$$

$$\text{Avg. Conc. (uc/cc)} = \frac{(\text{uc})}{\text{flow } (\text{ft}^3/\text{m}) \times \text{time (m)} \times 2.8 \times 10^4 \ (\text{cc}/\text{ft}^3)}$$

$$= \frac{8.84}{6000 \times 7 \times 24 \times 60 \times 2.8 \times 10^4}$$

$$= \frac{8.84}{1.69 \times 10^{12}}$$

$$= \boxed{5.2 \times 10^{-12} \text{ uc/cc}}$$

IV. ENVIRONMENTAL EVALUATION

A. Problem

1. A reactor is delivering radioactive waste to a public stream. The effluent contains a known concentration of each of several isotopes. How would you evaluate the practice in terms of

safety to downstream users of the water? Give the steps and additional data which would be required, or at least desirable for a proper assessment.

2. How would your assessment differ if the reactor were a government-operated reactor not subject to licensing requirements?

B. Solution

1. As a licensee, the reactor operator is required to control the concentrations of radionuclides in the liquid effluent to the MPC_w for 168 hours public exposure. Where a mixture of nuclides is present, the combined effect must be evaluated for all organs of concern.

$$\Sigma \frac{c_i}{MPC_i} \leq 1$$

where c_i is concentration of nuclide (i) and MPC_i is 168 hour public MPC_w for nuclide (i) for the organ being considered.

If the licensee wishes to discharge concentrations higher than permitted by the MPC's, he can appeal to the AEC for special permission. He must first evaluate the proposed increased discharge in a manner similar to that required for an AEC contractor. He must then convince the AEC that no one will be consuming water at concentrations over MPC_w or that they will be exposed to external radiation exceeding the allowable public rates.

2. As a contractor, the operator need not restrict the effluent concentrations to MPC_w at the point of release, but may use the point of water use as the place to evaluate the safety of the disposal practices.

He must, however, still use the formula -

$$\Sigma \frac{c_i}{MPC_i} \leq 1$$

at the point of water use by the general public. He must also consider all organs of the body.

In addition, he must evaluate other possible modes of exposure either by calculation or direct sampling and/or monitoring. These modes include:

(a) Accumulation of radioactive materials in municipal water plant

(b) Reconcentration of nuclides in fish and ducks

(c) Contamination of produce irrigated by the receiving stream

(d) Contamination of irrigated pasture and subsequent contamination of meat or milk products

(e) External exposure to people who use the stream for recreation.

This evaluation must also include the combined effects of all the above items on all possible body organs.

Waste Disposal

1. Concentrate & Contain
2. Dilute & Disperse
3. Delay & Decay

Waste Classes

1. Gaseous < Noble / Halogens / Particulates / Other
2. Liquid
3. Solid

99.5 - 99.9

Waste Categories

1. Low $< 5 \times 10^{-5}$ uc/cc
2. Intermediate $> 5 \times 10^{-5} - 10^{2}$ uc/cc
3. High $> 10^{2}$ uc/cc

EFFECTS OF RADIATION ON LIVING TISSUE

Study Notes

I. Structures and Activities of Living Cells

All living tissues are composed of large numbers of microscopic units we call cells. Despite their small size (10 to 20 microns in diameter), individual cells are complex structures containing many different components. Each cell is enclosed in a tough outer covering called the cell membrane. Inside the cell membrane is a viscous or jelly-like mass called protoplasm, the actual living matter of the cell. Properly, the protoplasm is composed of two major parts; the cytoplasm, which fills most of the cell volume, and the nucleus which is a small round body suspended in the cytoplasm. The sketch below illustrates these gross cell structures of an idealized cell.

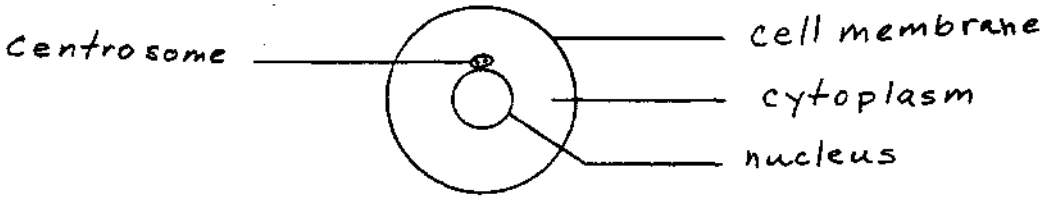


Figure 1. Gross Structures - Idealized Cell

The cytoplasm contains many complex chemical substances as well as fat droplets and several special structures.

These structures are involved in the production of vital chemical substances necessary to the life of the cell and to the organism of which the cell is a part.

The cell nucleus is in a sense, the control center of the cell, and contains a number of special structures important in carrying out control functions. The more important of these are the chromosomes and the nucleolus. These structures are suspended in a viscous fluid called the nucleoplasm which fills most of the volume of the nucleus. A nuclear membrane encloses the nucleoplasm and separates it from the surrounding cytoplasm. the following sketch illustrates the major nuclear components.

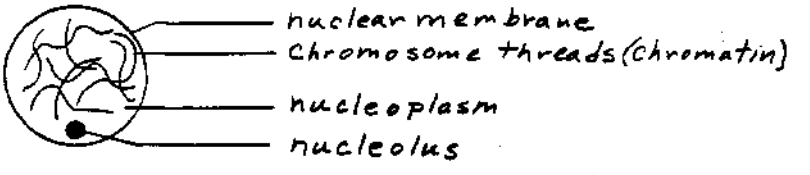


Figure 2. Major Nuclear Components - Idealized Cell

The chromosomes control the hereditary characteristics of the cell, so that cells which reproduce will form cells having the same characteristics. Each chromosome is a long slender structure composed of many smaller parts called genes, each of which has an effect on some individual function or characteristic of the cell containing it. Human body cells normally contain 46 chromosomes (arranged in 23 pairs), though some individuals appear to have 47 or 48 due to the separation of one or two chromosomes into two parts. Each chromosome may contain from a few hundred to as many as 1000 genes. The total number of genes in human cells is believed to be about 60,000. The genes are arranged in a particular order along the length of the chromosomes, so that the genes controlling a given characteristic, eye color for example, are always found in the same location in one particular chromosome.

Each cell carries on particular activities which are dependent upon the kind of tissue to which it belongs. The human body contains four different kinds of fixed tissue; connective, epithelial, muscle, and nerve. The mobile cells of the blood and lymph form a separate category. Connective tissues include sinews, tendons, bone, fat, major parts of some glands, etc. Epithelial tissues include the skin, and the linings of body cavities and organs. Muscle tissues include the skeletal muscles, the majority of the heart, the diaphragm, and major structures of the stomach and intestines, as well as a few other specialized tissues. Nerve tissues include the sensory receptors, the central nervous system, the brain, and additional connecting nerve cells.

Each cell has a fairly typical lifetime which is dependent upon its function and the particular tissue to which it belongs. Cell lifetimes in the human body vary from a few weeks in the case of the red blood cells (erythrocytes) to many years in the case of the cells of the brain and central nervous system (neurons). In healthy tissue, cells which die of "old age" are normally replaced by nearby cells of the same type through the process of cell division. The importance of this function may be readily appreciated when one considers that the 25 trillion red blood cells of the human body have an average life of only 110 to 120 days. To maintain the body in a normal state of health requires replacement of these cells at the rate of about 133 million per minute. While other body cells are replaced at slower rates, most of the 140 trillion body cells of a healthy adult human are replaced within a period of a few years.

During the intervals (interphase) between cell divisions, the cells carry on their normal functions, which always include the production of vital chemicals, and may include other functions as well, such as the contraction of muscle cells, and the transmission of electrical impulses by nerve cells.

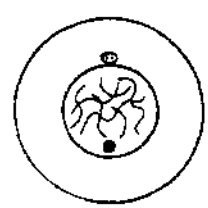


Figure 3. Interphase

This is the so-called "resting state" between cell divisions. The cell does not really rest during this phase, however. It engages in production of vital chemical substances necessary to its life and the life of the organism to which it belongs. To illustrate this further, let us take the example of a specific organ, the thyroid gland of the human body. Its major function is the production of thyroxin, a chemical substance we call a hormone, whose function is to regulate the chemical activity, or metabolism, of the body. Thyroxin is actually produced in minute quantities in individual cells which make up the gland. The total thyroxin production of these cells is the production of the gland. Since the gland contains millions of cells, the thyroxin production is substantial. However, because of the tremendous changes necessary for cell division, thyroxin production is suspended in those cells undergoing division. When the cells complete division, they resume thyroxin production. Fortunately, only a fraction of the cells are dividing at one time. The rest are all in the interphase state. (In the interphase state, the cells also exchange oxygen, carbon dioxide, water, and breakdown and build up fat and protein molecules necessary to cell life.)

Cell division is actually composed of two parts; cleavage of the cytoplasm, and nuclear division, or mitosis. However, it has become common practice to refer to the entire process of cell division as mitosis. Mitosis proceeds in four general phases; 1) prophase, 2) metaphase, 3) anaphase, and 4) telophase. Simplified sketches and descriptions of the four phases of mitosis follow (for simplicity, only four pairs of chromosomes are shown):

Figure 4. Prophase (early stage)

During the initial stage of cell division, prophase, the cell contracts, assuming a more rounded form. The chromatin threads contract into visible and separate elongated structures called chromosomes, which gradually split along their entire length, forming a pair of chromosomes, which remain attached to each other at a few points. Each member of this pair is called a chromatid. The nucleoli become fainter and eventually disappear. The nuclear membrane then contracts, and suddenly disappears. At about this time, a lens-shaped structure called the spindle forms in the cytoplasm from the centrosome, a small body normally located in the cytoplasm near the nucleus. The centrosome divides into two parts which move to opposite sides of the cells to form the poles between which the spindle fibers and chromosomes are arranged.

Figure 5. Metaphase

During metaphase, a connection is made to each chromosome by one of the spindle fibers at a small body called the centromere of the chromosome. This is the only point at which the chromatids in each pair are still attached. The chromosomes line up in a flat plane in the middle, or equator of the cell.

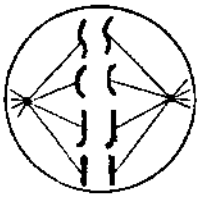


Figure 6. Anaphase

In the next stage, anaphase, the chromatids or daughter chromosomes begin to separate, gradually moving from their equatorial position to opposite poles of the spindle. When they reach their new positions at the poles, they form into a compact mass.

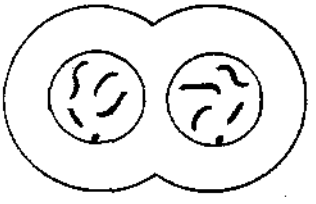


Figure 7. Telophase

During early telophase, the new nuclear membranes form around the two masses of chromosomes. The outer cell membrane draws in at the equator, accompanying cleavage of the cytoplasm. In late telophase, the membranes form completely around the two daughter cells, separating them. The chromosomes loosen, spread out, and eventually resume the faint thread-like network of chromatin seen in interphase. The nucleolus appears in the nucleus and mitosis is complete.

A special kind of cell division called meiosis occurs in the male and female reproductive organs. This process is sometimes called "reduction division", since its purpose is to reduce the number of chromosomes in reproductive cells to one set of 23. Since each child receives a set of 23 from each of his parents, his cells will have 23 pairs, or a total of 46. If meiosis did not take place, each generation would have double the number of chromosomes of the preceding generation. The simplified sketches below illustrate the process of meiosis.

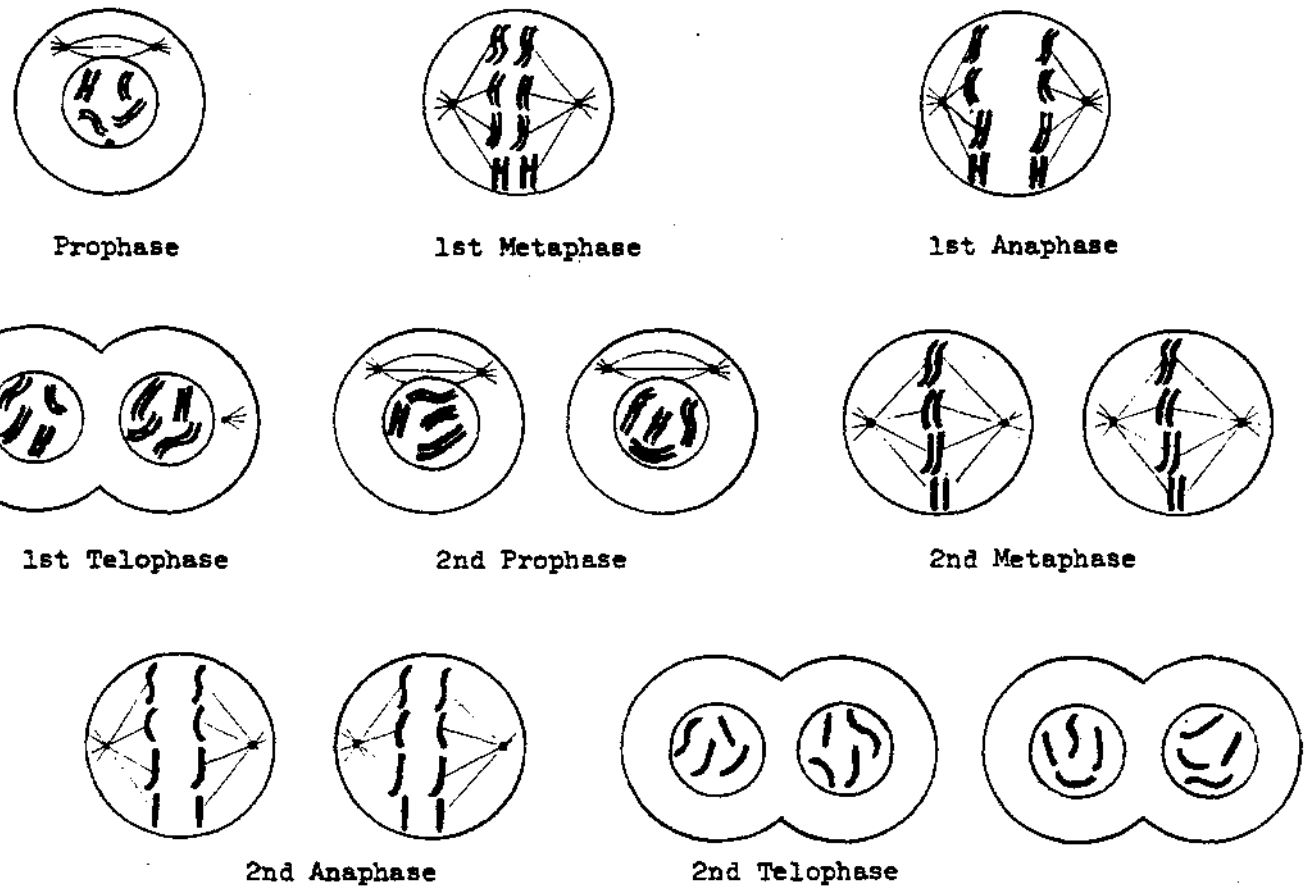
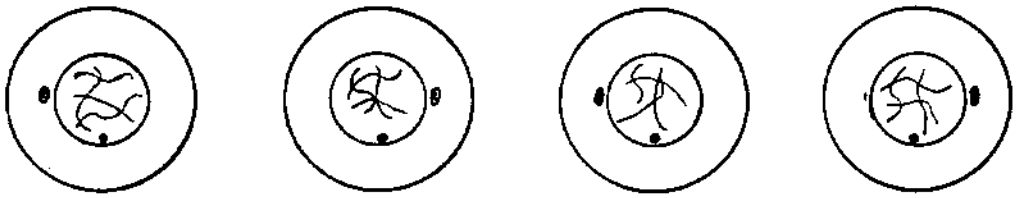


Figure 8. Meiosis



Mature Reproductive Cells
(gametes)

Figure 8. Meiosis (continued)

As will be noted from the above sketches, the initial cell, starting with four pairs of chromosomes has divided into four cells each having a single set of four chromosomes.

II. Fundamental Damage Effects

While the above descriptions are brief, it will be recognized that most activities of living cells are very complex. Cell activities follow a definite pattern, both in the production of vital chemicals and in the process of division. Anything which disturbs this pattern of activity at any point disrupts the normal life of the cell. If the disturbance is sufficiently great, the cell will suspend normal activities and attempt to repair the damage so that it can resume its regular functions. However, if the damage is beyond the ability of the cell to repair, it will die.

Many disturbances can result in the death of cells. A reduction in oxygen supply, inadequate supply of vitamins, a hormone imbalance, reduction in food supply (blood sugar), etc., may all result in the death of some body cells. Every time a person is bruised, cut, burned, has a disease (even a cold), or overexerts himself, some cells die as a result. So long as the damage is not too great, the dead cells are replaced by other similar cells as the result of division of nearby healthy cells. If the damage is too great, the dead cells will be replaced mainly by scar tissue cells which enter the damaged area.

The effects of ionizing raditions on living cells are not known in every detail. However, it is recognized that both the ionization and excitation of atoms within the cells are harmful to the cells' normal activities. Many of the changes are associated with the ionization or "activation" of water molecules in the cells. This results in the formation of free oxygen and hydrogen, (O°, O_2°, H°, and H_2°) OH° and HO_2° radicals, and hydrogen peroxide (H_2O_2). None are normal components of cells, and are injurious to the cells, since they act as strong oxidizing agents and will upset the normal chemical processes of the cells.

Some of the other effects on cells result from the disturbance of the complex chemical activity due to direct ionization or activation of atoms in the vital chemicals produced by the cells. Slight changes in some of the molecules of these vital chemicals can change them into useless substances or poisons, seriously upsetting or killing the cell. Dead cells release toxic substances which can be harmful. Where large numbers of cells in a tissue are killed due to a large local dose of radiation, the toxic substances released may be transferred to other locations in the body, injuring cells in tissues which have not been irradiated.

It is interesting to note that when a cell has a deficient supply of oxygen, it is less susceptible to radiation damage, mainly because $HO_2^{\cdot}$ radicals are less likely to be formed in the cell. This has lead to research on the development of so-called "radio-protectant" compounds which reduce the oxygen supply in the cells of the body. So far, such research has not been too effective, partly because other damage occurs anyway, and partly because the general reduction in oxygen supply to the entire body causes other harmful effects.

Damage to individual cells is dependent both upon the total number of ionizing events occurring within the cell, and their location within the cell. Alpha particles are particularly damaging to living cells because of their large ionization potential, and their short range. A typical 5 Mev alpha particle has a range in tissue of about 100 microns (μ) or less. Since one of these particles has the potential of creating about 150,000 ion pairs, this means that it would cause about 30,000 ionizations within a given cell. This is sufficient to cause appreciable damage. In contrast, a comparable beta particle has a much greater range in tissue and will cause a much smaller number of ionizations (on the average) in the individual cells through which it passes. Even though a 5 Mev beta particle would have the same ionization potential as a 5 Mev alpha particle, it would be less likely to seriously damage living cells than the alpha particle. The energy transfer per unit length of path (linear energy transfer) is much greater in the case of the alpha particle. It is for this reason that alpha particles have a greater relative biological effect than do beta particles or gamma rays.

It should be noted here that biological damage is due to both ionization and excitation. Ionization involves knocking electrons out of the outer orbits of atoms. This may in some cases cause an atom to break loose from a chemical compound of which it is a part. Excitation involves raising an orbital electron of an atom into a higher energy state, making the atom more chemically reactive. This may result in the atom breaking loose from a chemical compound of which it is a part, or it may cause the atom to bond to another atom, forming a different, and sometimes unusual compound or chemical radical. The effects of both of these reactions are probably about equal in importance. However, in biological systems, somewhat more of the radiation energy is believed to be transferred as excitation.

Two particulary harmful kinds of damage which result in delayed effects are chromosome breakage and gene mutation. When chromosome breakage occurs, the cell usually does not die. However, when it later attempts to divide,

it may not be able to complete the process, then degenerates and dies. Sometimes, a cell may complete the process, but be unable to properly transfer the broken chromosome pieces, so that one daughter cell has extra pieces, and the other is missing portions of one or more chromosomes. Such cells may divide several times before finally degenerating and dying.

Gene mutation is a more subtle effect, but may be equally harmful. Each gene is composed of a large number (probably millions) of individual atoms arranged in a complex organic molecule. The removal or addition of a single atom may change the characteristics of the gene markedly. So can the substitution of one kind of atom for another; e.g., the substitution of an oxygen atom for a nitrogen atom. In the body (somatic) cells of an individual, the funtion of the genes is to control a specific process in the production of some vital chemical, or to control gas exchange, water exchange, etc. If the gene is damaged, it may no longer carry on this function properly. If the effect is not too great, the cell may gradually deteriorate and die. In some cases, cells which have received such damage carry on an apparently normal existence for many years, then begin acting in an abnormal manner, growing rapidly. These may develop into tumorous growths which in some cases can be malignant.

When the gene mutation occurs in a reproductive cell, the changed characteristic will be transmitted to all the cells of the individual who results from the reproductive cell. If the mutation is of a minor nature, it may result in a change in hair or eye color or some other equally harmless effect. However, mutations may also result in harmful effects ranging from diabetes, hemophilia, etc., to serious physical malformations. The "hidden" conditions such as diabetes are much more common than the more obvious conditions such as physical deformities.

III. Somatic Effects

Since cells engaged in mitosis are carrying on a very complicated process, and have suspended their normal chemical production functions, they seem to be more sensitive to radiation damage than they are during interphase (in some cases, as much as 1000 times as sensitive). The effect of this is to make body tissues more sensitive to radiation when they contain large numbers of cells engaged in mitosis. It is for this reason that exposure to large radiation doses, on the order of 100 rems, show such distinct effects on the bone marrow, while most other tissues show lesser effects. For the same reason, rapidly growing young organisms are more sensitive to radiation than those which have reached the adult state. Body tissues, such as the brain, which show very little cell growth once an individual reaches the adult state are relatively insensitive to radiation. The same is true of the other cells of the central nervous system. Muscles also show relatively little cellular growth in an adult, and as a result are not very sensitive to radiation. On the other hand, the cells of the lining of the GI tract, the skin, and of the reproductive organs are all relatively sensitive to radiation.

Because all natural phenomena occur in a normal distribution pattern, the response of a particular individual to a given radiation dose cannot be predicted beforehand. Most people and other animals are able to withstand

relatively large acute doses (up to 100 rems) of radiation without serious effects, other than some possible slight life shortening due to premature aging or leukemia. However, in any group of organisms, including humans, some small number of individuals will be especially sensitive to radiation. Conversely, a small number will be unusually resistant to radiation. Because exact response cannot be predicted for an individual, in study of lethal doses of radiation, biologists have adopted the values for "LD 50/30", which remain remarkably consistent for large groups of organisms. This terminology refers to the acute dose of radition which will be lethal to 50% of the organisms within 30 days after the exposure. The chart below shows the approximate normal distribution curve for LD 50/30 for humans:

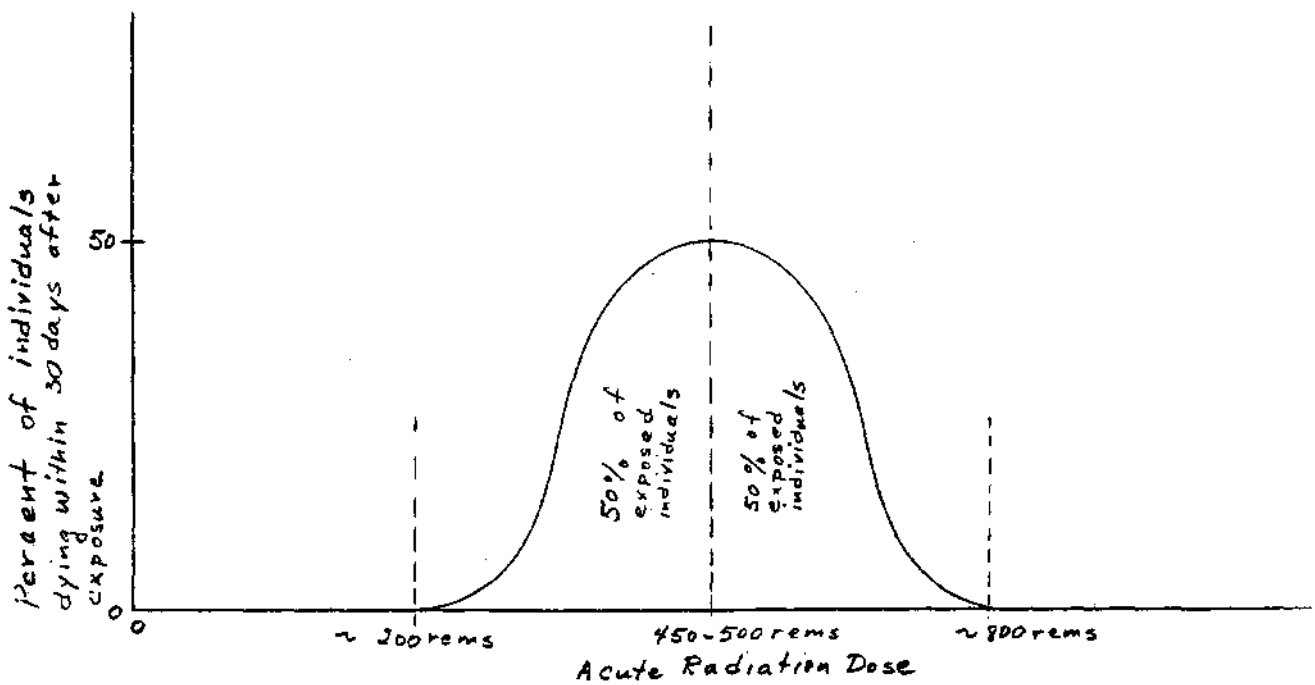


Figure 9. LD 50/30 For Humans

The same kind of curve will be seen when a graph is made of any other characteristic of large numbers of humans, such as height, weight, IQ, resistance to disease, reaction time, and so on. Fortunately, no one individual will be at the low end in all cases.

When an individual is exposed to a large radiation dose, he exhibits a characteristic group of symptoms, called the "radiation syndrome". However, all of these symptoms are common to other illnesses. It is only the particular combination that is characteristic of radiation sickness. For example, nausea, vomiting, and diarrhea are common symptoms of exposure to large radiation doses appreciably greater than 100 rems. However, the same symptoms are also seen in severe gastro-intestinal infections and other physical disorders of several kinds. The same is true of other symptoms noted in response to acute exposures to large radiation doses.

The typical group of symptoms seen in persons who have received a lethal or near-lethal radiation dose is as follows:

1. Nausea, vomiting and diarrhea within the first few hours.
2. No definite symptoms for a period of one to two weeks (latent period).
3. Second to third week
   Loss of appetite
   General malaise (tiredness, fatigue)
   Fever
4. Third to fourth week
   Hemorrhage
   Nosebleeds
   Pallor
   Inflammation of mouth and throat
   Diarrhea
   Petechiae and purpura (localized hemorrhages under the skin, resulting in spots of color due to the blood which remains in the tissues)
   Emaciation (loss of weight)

Most of those who live through the fourth week will eventually recover, though some permanent disability will probably remain in the more severe cases. For example, some permanent loss of hair from skin areas exposed to large radiation doses (several hundred rems) is common. Other persistent effects may be fatigue, poor appetite, partial or complete sterility, anemia, low resistance to disease, etc.

In addition to these generally chronic conditions, there are several possible delayed effects. Among these are leukemia, and tumor formation. These conditions usually do not appear until many years after the exposure. In the case of leukemia, the induction period is normally 3 to 5 years or more. In the case of fixed tumors, the induction period is usually 20 to 30 years.

In some cases, fixed tumors may be malignant, or "cancerous". In such cases, the tumor not only increases in size, but also invades healthy tissue, and often spreads by metastasis. In metastasis, small clumps of malignant cells break off from the main tumor and float through the blood stream or lymphatic system until they lodge in some spot. They continue to grow there, forming another tumor.

Radiation is often used in treating malignant tumors, especially those which are so located that surgical removal is difficult or impossible. Radiation is an effective medical weapon against malignant cells because of their rapid rate of growth and lesser ability to repair damage than healthy normal cells. As noted above, cells are more susceptible to radiation damage when engaged in mitosis, and tissues containing large numbers of dividing cells are most sensitive to radiation. Because radiation may cause malignant growths in addition to curing them, it has been called a "two edged sword".

IV. Genetic Effects

The fundamental aspects of gene mutation have been described above. Well-documented evidence of the mutagenic characteristics of radiation stems from the early research of H. J. Muller, beginning in the mid 1920's. His

studies involved exposure of common fruitflies (drosophila melanogaster) to various doses of radiation, and observing the effects upon their offspring. After some study, he was able to determine the radiation dose - mutation relationship for fruitflies. Since all natural populations show some spontaneous mutation, Muller expressed the mutagenic effects of radiation in terms of the dose required to double the natural mutation rate. For the fruitfly, this is an acute dose of about 50 R. Muller was also able to demonstrate a linear dose - mutation effect at increased doses. In other words, tripling the dose tripled the increase in mutation rate, etc. Recent studies have shown that when a dose of radiation is given in small increments over a long period of time, the mutagenic effect is much less than that of the same dose given in an acute exposure.

The ultimate harmful effects of mutation are expressed in the production of weakened individuals. Unfortunately, much still needs to be known about mutation in man. While we do have good information on some genetic diseases of man, such as diabetes, pernicious anemia, sickle cell anemia, muscular dystrophy, etc., we are still unable to define all the mutations occurring naturally in man. Neither are we able to define the mutagenic radiation doses as well for man as we would like.

In general, genetecists consider all mutations harmful. While this is not strictly true, less than 1% of those observed in experiments appear to result in stronger, more capable organisms. All the rest appear to result in weaker ones. However, in most cases an individual is protected by receiving a normal gene of a particular kind from one parent to match with a defective gene from the other parent. In this event, the individual suffers little or no ill effects. A good illustration of this may be found in the case of diabetes. If an individual inherits diabetes genes from both parents, he will suffer severe diabetes, beginning in his early childhood. If he inherits a healthy gene from one parent, and a diabetes gene from the other, he may never feel any ill effects. However, it is common for such individuals to exhibit a mild case of diabetes, beginning in middle age.

Every individual is believed to carry a few (about 8) mutant genes, transmitted to him by his parents. During his lifetime, he is exposed to many influences such as chemicals, excessive heat, radiation, etc., which add a few more. However, where random mate selection exists, as it does in most populations, the probability of both of a child's parents having exactly the same mutant genes is small. This may be readily recognized when one remembers that humans have on the order of 60,000 genes. One additional factor which tends to minimize the transmission of mutant genes is that more than 60% of all children are born to parents under age 30, and more than 75% are born to parents under age 40. This tends to minimize transmission of the mutant genes acquired by the parents during their lifetimes.

So far as the overall effects of mutation are concerned, geneticists do not consider it a significant problem to persons working with radiation, unless the acute doses are very large (as in radiation accidents). The probability of a radiation worker's children receiving matched mutant genes from both parents is small. However, radiation exposure does add to the

pool of mutant genes in a population, and eventually will result in some increase in the numbers of individuals born with genetic defects. It makes no difference whether a small portion of the population carries a greatly increased load of mutant genes, or the entire population carries a slightly greater than normal load, the ultimate effect will be the same. There will be an increase in the numbers of persons born with genetic defects which is proportional to the total increase in mutant genes in the entire population.

For this reason, it is desirable to control the radiation dose in such a way that mutagenic effects are minimized. This is accomplished in this country through establishment of separate sets of radiation limits for persons engaged in radiation work and members of the general public. Those established for the public are generally 1/10 those established for persons occupationally exposed to radiation.

As a reminder, radiation does not cause any new mutations different from those which occur naturally. It only causes an increase in the total number. There are many mutagenic (and carcinogenic) agents in addition to radiation, and new ones are discovered frequently. Occupational radiation exposure is currently believed to represent a small factor in adding to the mutations in the genetic pool of the general population. Mutant genes must be paired for an individual to suffer the full effects of the genetic defect.

EFFECTS OF RADIATION ON LIVING TISSUE

I. STRUCTURES AND ACTIVITIES OF LIVING CELLS

- A. Major Structures
  - 1. Outer Cell Structures
  - 2. The Nucleus
- B. Structures Controlling Heredity
  - 1. The Chromosome
  - 2. The Gene
- C. Normal Cell Activities
  - 1. Production of Vital Chemicals (resting state)
  - 2. Mitosis, or cell Division
  - 3. Meiosis or reduction division (reproductive cells only)

II. FUNDAMENTAL DAMAGE EFFECTS

- A. Specific Changes in Cell Components
- B. Effects Upon the Life of Individual Cells

III. SOMATIC EFFECTS

- A. Effects Upon Individual Organs or Tissues
- B. Whole Body Irradiation
- C. Delayed Effects
- D. Cancer

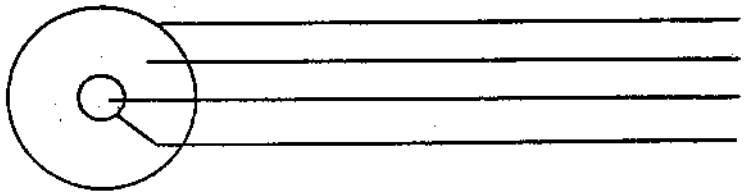
IV. GENETIC EFFECTS

- A. Mutation
- B. Experimental Data
- C. Probable Effects Upon the General Population

EFFECTS OF RADIATION ON LIVING TISSUE

QUESTIONS

1. In the sketch below of a typical living cell, label the major components as indicated:



2. Chromosomes are important structures involved in control of the heredity of cells. They are located in _____ of the cell.

   a) the genes
   b) the cytoplasm
   c) the nucleus
   d) the genes, nucleus and cytoplasm
   e) only the nucleus and cytoplasm

3. The number of chromosomes in living cells is a characteristic of the species to which the animal or plant belongs. Human body cells normally contain _____ chromosomes.

   a) about 10,000
   b) about 1000
   c) 46
   d) 28
   e) 100
   f) 32

4. The genes are also a very important structure in the heredity of cells. Which of the following statements about them is true? (Underline)

   a) The genes are located in the chromosomes.
   b) The chromosomes are located in the genes.

5. The number of genes is about the same as the number of chromosomes.

   True _____ False _____

6. A typical living cell is about _____ in diameter.

a) 1/1000 mm
b) 1/10 mm
c) 1/32 inch
d) 1/100 inch
e) 1/50 mm
f) 1/50,000 inch

7. There are about _____ living cells in the body of a typical adult human being.

a) one million
b) 170 million
c) one billion
d) 500 billion
e) one trillion
f) 140 trillion

8. Cells are most sensitive to radiation while engaged in mitosis (or cell division).

True _____ False _____

9. In human cells, after mitosis each of the daughter cells has _____ chromosomes, and after meiosis each of the daughter cells has _____ chromosomes.

a) 24
b) 32
c) 1000
d) 10,000
e) 64
f) 46
g) 23
h) 48
i) 52

10. a) What do the abbreviations LET and RBE stand for?

b) Is the distribution of ionizations within a small volume of a cell important?

Yes _____ No _____

11. Is ionization of the atoms making up body cell structures primarily responsible for the biological effects of radiation?

Yes _____ No _____

12. a) Radiation injures tissues in two ways; by "direct action" and "indirect action". In general usage, "direct action" means a tissue is injured directly by the radiation, and "indirect action" means that poisons from another irradiated tissue are affecting a non-irradiated tissue.

True _____ False _____

b) What is activated water?

c) The fact that the "oxygen effect" is seen in both single cells and mammals means that the action of radiation which causes the heaviest damage is _____.

1) direct b) indirect c) neither

13. What relationship is there between radiation damage to a single cell and damage to the whole body?

14. A dose of 200 rads would make many people ill (a few dangerously so). Since this dose of radiation represents an amount of energy which will raise the temperature of water by only 1/2000 of one degree centigrade, why is it so damaging to living tissue?

15. a) "Radiation sickness" has a number of symptoms which are characteristic of it, and are not found in other illnesses.

True _____ False _____

b) List some of the symptoms which may be displayed by an average man who has received an acute radiation dose in the neighborhood of 200 R to 500 R.

16. a) What is the meaning of the term "LD 50/30", and what is its value for man?

b) Has a Maximum Permissible Exposure been established for acute external exposure to man? If so, what is it?

17. The target theory of biological effect of radiation states that _____.

a) if a single particle or ray hits a cell target, the cell will die.

b) a cell contains a small especially sensitive volume (or target) in which ionization must occur to injure the cell.

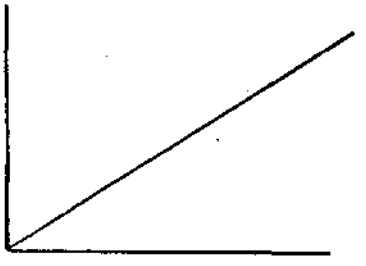
c) there are several targets in a cell, and if one of them is hit, the cell will be injured.

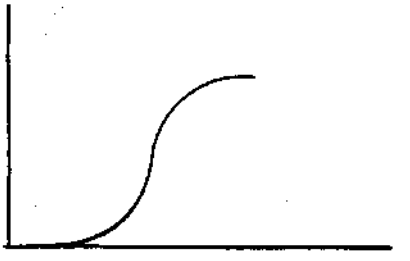
18. a) What is the name applied to a gene which has undergone a change (due either to radiation or some other cause)?

18. b) Ionizing particles may cause major damage to a chromosome as a whole. One kind of injury which has particularly serious effects upon later division of the cell containing the chromosome is _____.

1) chromosome mutation
2) chromosome ionization
3) chromosome duplication
4) chromosome activation
5) chromosome breaks
6) changing the chromosome into chromatin

19. a) If we plot radiation dose vs. effect on a graph, we get two different curves for different kinds of effects. One of these is called a "linear" effect and the other a "threshold" effect. Label the two curves with the proper names, and name each of the graph axes properly.





b) Somatic effects are of the threshold type, while genetic effects are of the linear type.

True _____ False _____

20. Name two body tissues which are quite resistant to radiation, and two which are quite radiosensitive.

Radioresistant	Radiosensitive
_____	_____
_____	_____

21. a) In what tissue do erythema and epilation appear after localized irradiation? (Underline)

1) GI tract
2) blood forming organs
3) skin
4) muscel
5) brain
6) gonads

b) The lowering of the energy of the radiation _____ the threshold erythema dose

1) raises 2) lowers 3) does not effect

22. a) Irradiation of the GI tract (i.e., mouth, pharynx, esophagus, stomach, and small and large intestines) can cause decreased multiplication and secretion by the cells lining these organs. What would be the symptoms of a man suffering from this type of damage?

b) About _____ roentgens of external dose to the gonads will cause permanent sterility in most humans so exposed.

1) 50 to 100
2) 100-to 200
3) 200 to 400
4) 400-500
5) 500-600
6) 600-800

23. Why are living organisms (including man) able to withstand far greater total doses of radiation when received as chronic exposure than when received as acute exposure?

24. a) Ionizing radiation has been described as a "two-edged sword" (by Peter Alexander) in regard to its effect upon cancer. Can you explain this?

b) Radiation-induced cancer may show up within a few years after a serious overexposure.

True _____ False _____

c) What is the connection between somatic mutations and cancer?

25. a) Of which organ is the alveolus the chief functional unit?

b) Why is this organ of particular importance with regard to internal emitters?

c) Which isotope, found to a considerable extent in fission products, is concentrated in the thyroid gland?

d) Can the resulting irradiation of the cells of this gland lead to tumor production?

Yes _____ No _____

HAPO PROGRAMS IN RADIOBIOLOGY

Review of Experimental Animal Farm Program

L. K. Bustad

I. Brief History of Operation

II. Studies on the Biological Effects of Radioiodine in sheep, swine, goats, and cows. Emphasis will be on radioiodine-131 but studies involving I^{125} and Te^{132}-I^{132} will be mentioned.

III. Alpha and Beta irradiation of the skin stressing work on Sr^{90} and P^{32} plaques on sheep and swine skin, Ru^{106} particles and Pu^{239} injections in swine skin.

IV. Studies with Cs^{137} and Zn^{65} in sheep emphasizing the gonad dose.

V. Effects of bone-seeking radionuclides in miniature swine stressing the effects of Sr^{90} when fed daily to swine.

VI. Supplemental studies on milk, transfer studies of important nuclides, GI absorption of potential SNAP elements, and the toxicity of Np^{237}.

VII. Future studies

HAPO PROGRAMS IN RADIOBIOLOGY

Review of Radioecology Programs

F. P. Hungate

I. MICROBIOLOGY

A. Mainly theoretical attack on mechanisms involved in radiation damage to biological material.

1. Relative biological effectiveness of alpha and beta

2. Catalase, permeability, etc.

II. PLANT NUTRITION

A. Uptake of radionuclides by plants.

1. Relative uptake by laboratory tests.

Sr > I > Cs > Ru > Ce > Pu, etc.

River - Farm

2. Activity in river too low to measure (in 1950)

Small plots - milliacre (4 x 10)
Watered with well water, 5% effluent, 100% effluent.
Barely detectable difference at 100% level

B. Special Problems

1. Burst pipe - > 4 below surface - Sr^{90}

2. Can take isotopes as deep as 30-40'. Depends on plant species.

3. Zn^{65} - foliar vs. direct soil

4. I^{131} deposition on vegetation. 30-40% found inside leaf.
In fuel burn test 90% outside leaf. Particulate?

Rates of deposition
Retention - Factors influencing.

5. Sr^{90} and Cs^{137}

Undesirability of using ion pairs to express data.

III. RADIOECOLOGY

A. River problems

1. Indicator organisms

2. Migratory birds

   Dispersion of isotopes
   Nesting performance

3. Radionuclide transport by plankton

B. Alaskan Studies

1. Project chariot

2. Fallout levels

C. Fallout Levels in Browsing Animals

HAPO PROGRAMS IN RADIOBIOLOGY

Review of Aquatic Biology Programs

R. E. Nakatani

I. INTRODUCTION

A. Importance of Fisheries Resources

B. Impact of Introduction of Radionuclides into Aquatic Systems

II. PAST PROGRAMS -- July 1945-1950's

A. Reactor Effluent Monitoring - Genesis of Biology Laboratory

B. Radiobiological Surveys - Radioecology, Environmental Studies and Evaluation.

III. PROGRAMS OF MORE RECENT YEARS -- LATE 1950's - DATE

A. Somatic Effects of Internal Emitters in Fish

B. Bioassay of Industrial Chemicals

C. Swimming Performance of Fish Reared in Reactor Effluent

D. Calcium and Strontium Metabolism in Crayfish

IV. FUTURE PROGRAMS

A. Effects of Temperature on Metabolism of Aquatic Organisms

B. Adaptive Response and Performance of Fish With Body Burdens of Internal Emitters

HAPO PROGRAMS IN RADIOBIOLOGY

Review of Metabolism Programs

R. C. Thompson

I. GENERAL DESCRIPTION OF OBJECTIVES, FACILITIES, AND PERSONNEL

II. ABSORPTION, DISTRIBUTION AND RETENTION STUDIES

- A. Gastrointestinal absorption of Pu^{239}
- B. Distribution and Retention of Cs^{137}
- C. Discrimination between Ca and Sr

III. THERAPEUTIC REMOVAL STUDIES (EFFECT OF CHELATING AGENTS ON PLUTONIUM RETENTION)

IV. TOXICITY STUDIES

- A. Comparative toxicity of Pu^{238} and Pu^{239}
- B. Effects of radiation on the intestine

HAPO PROGRAMS IN RADIOBIOLOGY

Review of Inhalation Toxicology Programs

W. J. Bair

I. INTRODUCTION

- A. Areas of Interest
- B. Definition of Terminology

II. EXPERIMENTAL METHODS

III. EXPERIMENTAL RESULTS

- A. Deposition
- B. Retention, Translocation, and Excretion
- C. Biological Effects
- D. Therapy

IV. FUTURE WORK

RADIOCHEMICAL ANALYSIS

A discussion describing the application of current analysis techniques to the measurement of radioactivity in water, air, soil and biological samples. Conventional techniques and the more recent gamma energy pulse height analysis technique are described. The influence of variables and appropriate corrections are treated in some detail.

O U T L I N E

I. SCOPE OF RADIOLOGICAL ANALYSIS WORK

- A. Review of CY 1963 Performance
- B. List of Measurements Routinely and Infrequently Accomplished
- C. Methods of Analysis

II. SOME PROPERTIES OF RADIONUCLIDES

- A. Decay Schemes and Decay Rates
- B. Interaction of Radiation with Matter

III. RADIATION MEASUREMENTS

- A. Measuring Alpha and Beta particles
- B. Measuring Gamma Rays - Pulse Height Analysis

IV. STATISTICAL CONSIDERATIONS

- A. Reliability of Results
- B. Detection Limits

RADIOLOGICAL ANALYSIS

Scope of Work Accomplished, CY-1963

Sample Type	Analyses	No. Detn's
Test wells	Co-60, Sr-90, Cs-137, NO_3	~ 8,500
Milk, meats, produce thyroids, vegetation	P-32, Sr-90, I-131, other gamma emitters	~13,800
Fish, ducks	T_β, P-32, Sr-90	12,600
Columbia River,	T_α, T_β, U, RE+Y, Na-24 P-32, Sc-46, Cr-51, Cu-64, Zn-65, As-76, Sr-89/90 Sr-90, I-131, Np-239, Ga-72	6,100
Air samples, Stack Gases	T_α, T_β, C-14, S-35 I-131	10,300
Mud and Soil	T_β	400
Miscellaneous waters	T_α, T_β	1,300
Bioassay	T_α, T_β	6,200
	Total RPO	~59,200
All types	All kinds	90,900

LIST OF NUCLIDES MEASURED

Routine Measurements (RPO)	Other Measurements (Infrequent or Non-RPO)
Uranium	Sodium ion
Nitrate ion	C-14
T_α	Na-22
T_β	Si-31
H-3	S-35
Na-24	Cl-38
P-32	A-41
K-40	Ca-45
Sc-46	Mn-54
Cr-51	Mn-56
Co-58	Fe-59
Co-60	Br-80
Cu-64	Kr-88
Zn-65	Rb-88
Ga-72	Sr-85
As-76	Y-88
Sr-89	Y-90
Sr-90	Ag-110
Zr-95	Sb-124
[Nb-95]	Sb-125
Ru-103	Te-131
Ru-106	I-129
[Rh-103]	I-132
[Rh-106]	I-133
I-131	I-135
Cs-137	Xe-133
Ce-141/144	Xe-135
[Pr-144]	Ba-140
Np-239	[La-140]
	Pm-147
	Au-198
	Hg-203
	Pa-223

METHODS OF ANALYSIS

I. SEPARATION, PURIFICATION, CHEMICAL

A. Distillation

B. Precipitation

C. Ion Exchange

D. Solvent Extraction

E. Fluorophotometer

F. Flame Photometer

G. Spectrophotometer

II. GROUP SEPARATION FOLLOWED BY COUNTING

A. Rare Earth Plus Yttrium Separation

B. Halides

C. Carbonates, Hydroxides

III. DIRECT COUNTING

A. Total Alpha

B. Total Beta

C. Gamma "Scan"

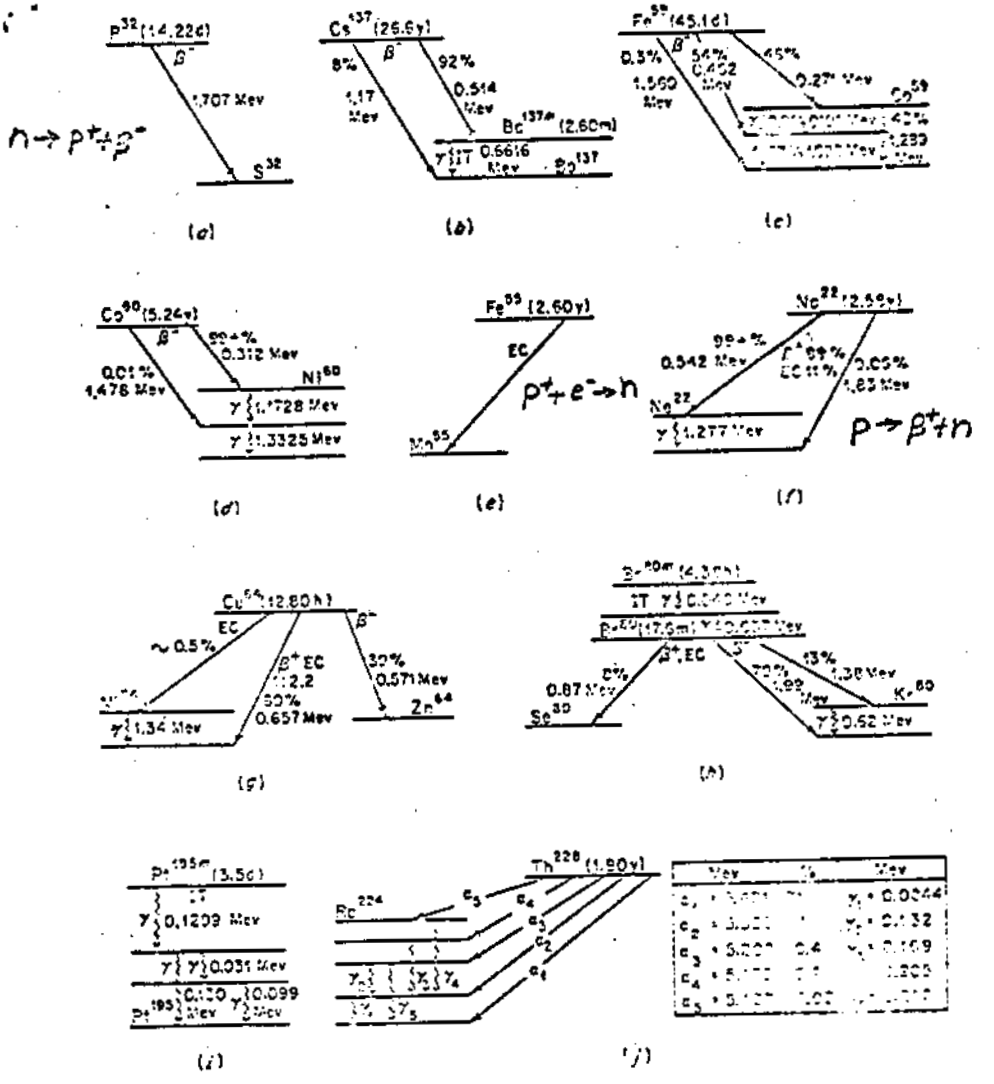


FIG. 1-4. Examples of decay schemes. [*Based on Strominger, Hollander, and Seaborg* (12).]

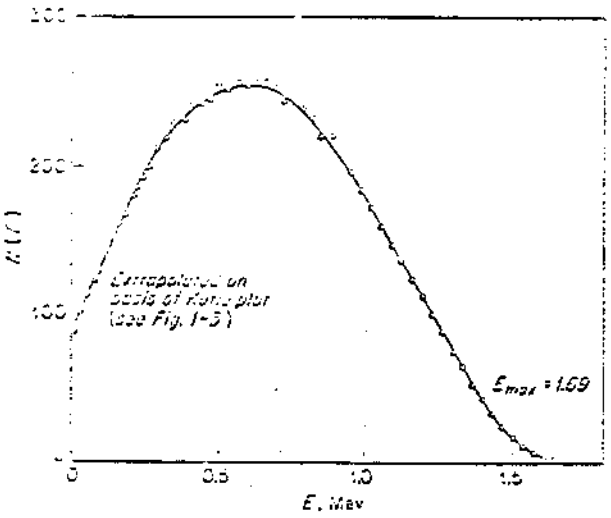


FIG. 1-2. Plot of the number of particles emitted from a sample of P^{32} as a function of their energy. [*From Kofoed and Drosi* (6).]

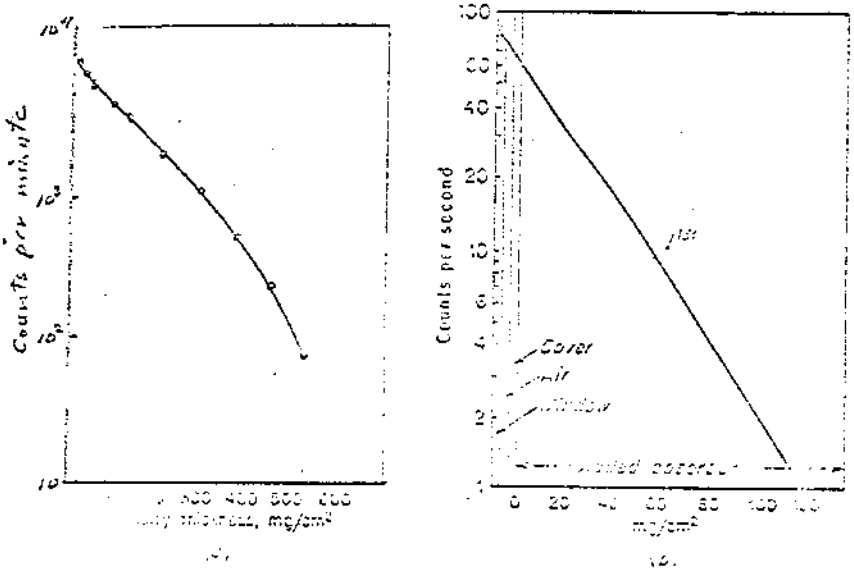


FIG. 6-1. (a) Beta-ray absorption in aluminum for pure-beta-emitting sources. (b) First portion of aluminum absorption curve for I^{131}, showing the method of correcting for absorption of air, counter window, and sample covering.

Beta Emitters by Energy and Half-Life

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New York, N. Y.

THIS TABLE can help identify unknown beta emitters whose half-life and beta energy have been determined by standard laboratory techniques. It also is a guide to beta-emitting isotopes for applications requiring specific half-lives and energies. (A similar table for gamma emitters is in preparation.) A more detailed compilation of nuclear data, such as National Bureau of Standards Circular 499 and Supplements, should be consulted for details of these emitters and their decay.

Emitters of conversion electrons and positrons as well as emitters of beta rays are included since all these particles produce similar effects when absorption methods are used to determine energy. Where an isotope can decay by emission of beta particles of different energies, the emitter is listed in the energy group corresponding to each beta, provided its contribution to total beta activity is greater than 5%. This is the lower limit of detection of typical absorption technique (Harley and Hallden, NU, Jan. '55, p. 32). All the betas from one emitter will lie in the same half-life interval.

Only isotopes with half-lives greater than 6 hr are listed; in general, a shorter half-life limits identification by the methods described.

Daughters with shorter half-lives than their parents are listed *in italic* under the half-life of the parent. In the natural series, the short-lived daughters are listed under the half-life of the nearest antecedent having a half-life over 6 hr. U^{237} (0.1–0.3 Mev, 5–10y) should be in italic.

* * *

All data used in this compilation are from National Bureau of Standards Circular 499, including Supplements 1, 2, and 3.

Half-life	E_{max} (Mev) 0–0.1	0.1–0.3	0.3–0.5	0.5–0.7
6–12 hr		Tm^{166} Bi^{204}	I^{135} Eu^{152} Ta^{180} Tl^{199} Pb^{212} Pa^{234}	Fe^{52} Zn^{62} Pd^{101} Er^{171} Ta^{186} Pb^{212}
12 hr–1 d		K^{43} Br^{76} Pd^{112} Pr^{142} Tb^{154} Au^{193}	I^{133} Ce^{135} Ir^{194} Np^{236}	Cu^{64} Ga^{72} Nb^{96} I^{130} Pt^{197}
1–3 d	Lu^{170} Ta^{177}	Zn^{72} Mo^{99} Ba^{135} Re^{186} Os^{193} Th^{231} Pa^{232} Np^{238} Np^{239}	Cu^{67} As^{76} Br^{77} Br^{82} Cd^{115} Sn^{121} Cs^{129} Tl^{200} Np^{239}	Sc^{44} As^{71} *Ge^{71}* As^{77} W^{187} Np^{239}
3–5 d	Tb^{157}	Te^{119} Te^{132} Eu^{146} Tb^{157} Yb^{175} Pt^{195}	Dy^{166} Yb^{175} Au^{199}	Sc^{47} Y^{87} I^{126}
5–10 d		Cs^{131} Tb^{153} Tm^{167} Lu^{171} Lu^{172} Lu^{177} U^{237}	I^{131} Xe^{133} Ho^{162} Er^{169} Lu^{177}	Mn^{52} I^{131} Cs^{132} Tb^{161} *Pb^{209}*
10–13 d	Ir^{190}	Ba^{131}	Ba^{140} Nd^{147} *Pb^{211}*	
13–15 d		Os^{191} Ra^{225}	Cs^{136} Eu^{149}	
15–20 d			Eu^{156}	
20–30 d	W^{179}	Th^{234} Pa^{233}	Ce^{141}	Ce^{141} Pa^{233}
30–40 d		Nb^{95}		
40–50 d	*Rb^{203}*	Fe^{59} Hg^{203}	Fe^{59} Ru^{103} Hf^{181}	Ru^{103}
50–100 d		S^{35} *Nb^{95}* Tm^{168}	Sc^{46} Co^{58} Zr^{95} Sb^{124} Tm^{168} W^{185}	Sb^{124} Tb^{160} Ir^{192}
100–150 d	W^{181}	Ta^{179}		Ta^{182}
150–200 d		Ca^{45} Lu^{174}		Lu^{174}
200–250 d			Zn^{65}	
250 d–1 y	Ru^{106} Ag^{110} Tb^{155}	Co^{57}	Ce^{144}	Ag^{110}
1–2 y	Tm^{171}	Eu^{155}	Sn^{121}	
2–3 y	Cs^{134}	Sb^{125}		Na^{22} Sb^{125} Cs^{134}
3–5 y		Pm^{147} *Lu^{173}*		
5–10 y	Ra^{228} Pu^{241}	Eu^{154} U^{237}	Co^{60}	Cd^{113} Eu^{154}
10–20 y	H^{3}			
20–30 y	Pb^{210} Ac^{227}			Sr^{90}
30–50 y				Cs^{137}
50–100 y	Ni^{63} Sm^{151}			
>100 y	Pd^{107} Nd^{150} Re^{187} *Ac^{227} Ra^{228}*	C^{14} Rb^{87} Tc^{99} I^{129} Cs^{135} *Th^{231} Pa^{233} Th^{234} Np^{238}*	Am^{242}	Be^{10}

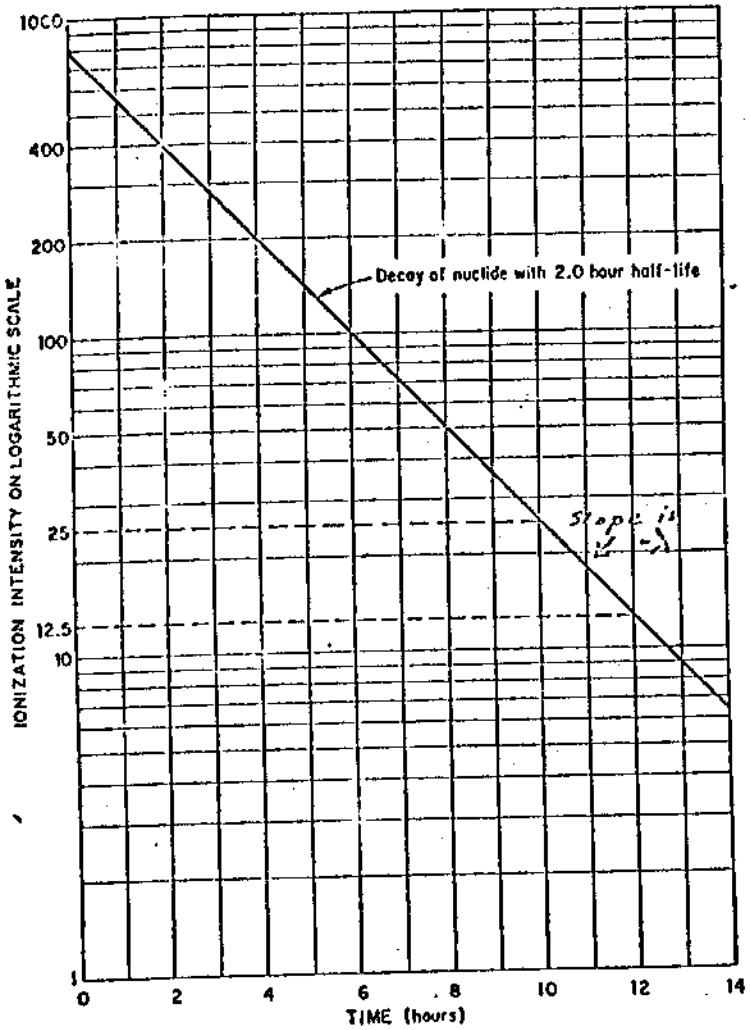


Fig. 2.3. Measurement of half-life from semi-logarithmic decay curve

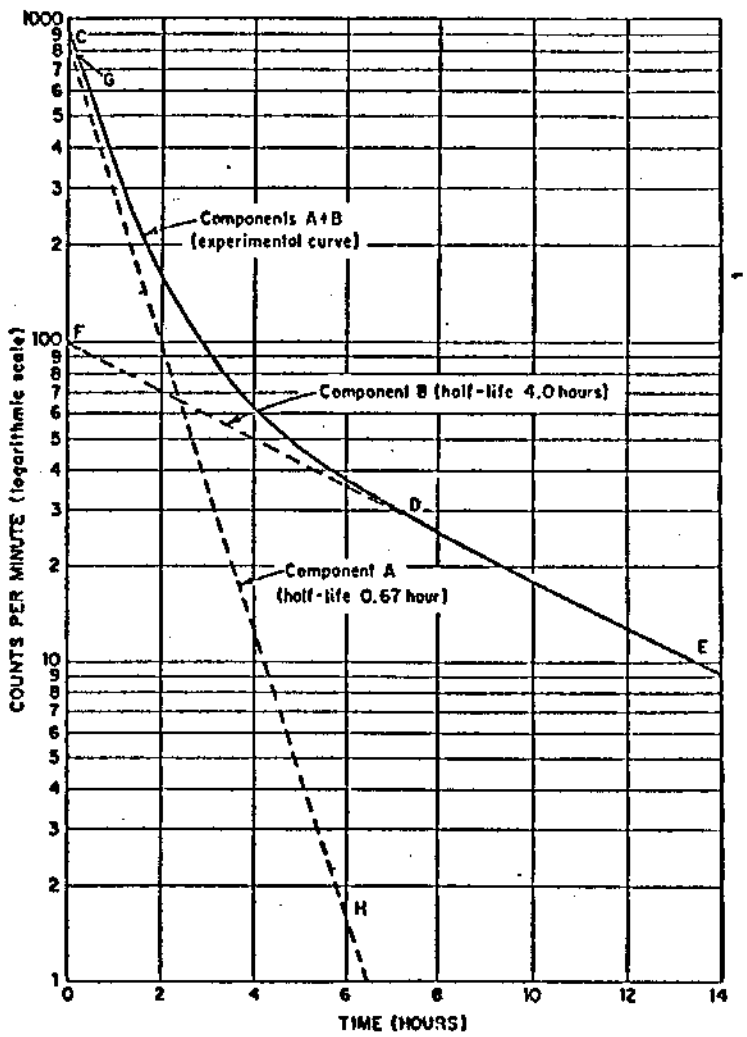


Fig. 2.4. Resolution of complex decay curve

ACTIVITY MASS RELATIONSHIP - SPECIFIC ACTIVITY

$$\text{Specific Activity (Sp A) in dis/sec/gm} = \frac{0.693\ N}{T_{\frac{1}{2}}} \qquad \left(-\frac{dN}{dt} = \lambda N\right)$$

N = number of radioactive atoms per gram and $T_{\frac{1}{2}}$ is the half-life expressed in seconds. $\lambda = \frac{0.693}{T_{1/2}}$

In calculating specific activity it is more convenient to use a variation of the basic equation, which is transformed as follows:

By def: N = Avogadro's number/atomic weight = $\frac{6.03 \times 10^{23}}{\text{atomic weight}}$

By def: dis/sec/3.7×10^{10} = curies

Substituting:

$$\text{Sp A} = \frac{.693\ N}{T_{\frac{1}{2}}\ (\text{in secs})} = \frac{.693}{T_{\frac{1}{2}}} \times \frac{6.03 \times 10^{23}}{\text{atomic weight}} \times \frac{1}{3.7 \times 10^{10}} = \text{c/gm}$$

This equation is satisfactory when the half-life of the nuclide whose specific activity is needed is expressed in seconds. If, however, the half-life is expressed in other units such as minutes, hours, days, or years, a separate time conversion is required for each. By substituting the appropriate time conversion factors as listed in the table of Conversion Factors in this Handbook the following five equations can be obtained.

(1) Curies/gram or Sp A ($T_{\frac{1}{2}}$ in secs) = $\frac{1.13 \times 10^{13}}{(T_{\frac{1}{2}})\ (\text{atomic weight})}$

(2) Curies/gram or Sp A ($T_{\frac{1}{2}}$ in mins) = $\frac{1.884 \times 10^{11}}{(T_{\frac{1}{2}})\ (\text{atomic weight})}$

(3) Curies/gram or Sp A ($T_{\frac{1}{2}}$ in hrs) = $\frac{3.14 \times 10^{9}}{(T_{\frac{1}{2}})\ (\text{atomic weight})}$

(4) Curies/gram or Sp A ($T_{\frac{1}{2}}$ in days) = $\frac{1.308 \times 10^{8}}{(T_{\frac{1}{2}})\ (\text{atomic weight})}$

(5) Curies/gram or Sp A ($T_{\frac{1}{2}}$ in yrs) = $\frac{3.59 \times 10^{5}}{(T_{\frac{1}{2}})\ (\text{atomic weight})}$

In making a calculation choose the appropriate equation as illustrated in the following example. Calculate the Sp A for Na^{22} whose half-life is 2.6 years. Choose equation (5) above, use the mass number as the atomic weight, and make the appropriate substitutions.

$$\text{Sp A} = \frac{3.59 \times 10^{5}}{T_{\frac{1}{2}}\ (\text{years}) \times \text{atomic wt}} = \frac{3.59 \times 10^{5}}{2.6 \times 22} = 6.28 \times 10^{3}\ \text{curies/gm}$$

The entry in the following table under the heading "grams per curie" is the reciprocal of Specific Activity in curies per gram and in this case $\frac{1}{6.28 \times 10^{3}} = 1.59 \times 10^{-4}$ grams per curie.

The values in the tables on the succeeding pages were calculated from equations (1), (2), (3), (4), and (5) above.

ACTIVITY MASS RELATIONSHIP - SPECIFIC ACTIVITY

ISOTOPE	HALF LIFE		CURIES PER GRAM	GRAMS PER CURIE
Th-232	1.39×10^{10}	years	1.11×10^{-7}	9.0×10^{6}
U-238	4.51×10^{9}	y	3.34×10^{-7}	2.99×10^{6}
U-235	7.1×10^{8}	y	2.15×10^{-6}	4.65×10^{5}
Cl-36	3.08×10^{5}	y	3.23×10^{-2}	30.9
U-233	1.62×10^{5}	y	9.51×10^{-3}	1.05×10^{2}
Ni-59	8×10^{4}	y	7.61×10^{-2}	13.1
Pu-239	2.436×10^{4}	y	6.17×10^{-2}	16.2
C-14	5568	y	4.61	0.217
Ra-226	1622	y	0.98	1.02
Cs-137	26.6	y	98.5	1.02×10^{-2}
Sr-90	27.7	y	1.44×10^{2}	6.96×10^{-3}
H-3	12.262	y	9.78×10^{3}	1.02×10^{-4}
Co-60	5.24	y	1.14×10^{3}	8.76×10^{-4}
Tl-204	3.56	y	4.94×10^{2}	2.02×10^{-3}
Fe-55	2.60	y	2.51×10^{3}	3.98×10^{-4}
Pm-147	2.64	y	9.25×10^{2}	1.08×10^{-3}
Cs-134	2.07	y	1.29×10^{3}	7.73×10^{-4}
Ru-106	1.00	y	3.39×10^{3}	2.95×10^{-4}
Ce-144	285	days	3.18×10^{3}	3.14×10^{-4}
Zn-65	245	d	8.21×10^{3}	1.22×10^{-4}
Ca-45	164	d	1.77×10^{4}	5.65×10^{-5}
Po-210	138.4	d	4.50×10^{3}	2.22×10^{-4}
Ta-182	115.1	d	6.24×10^{3}	1.60×10^{-4}
S-35	87	d	4.30×10^{4}	2.33×10^{-5}
W-185	75.8	d	9.32×10^{3}	1.07×10^{-4}

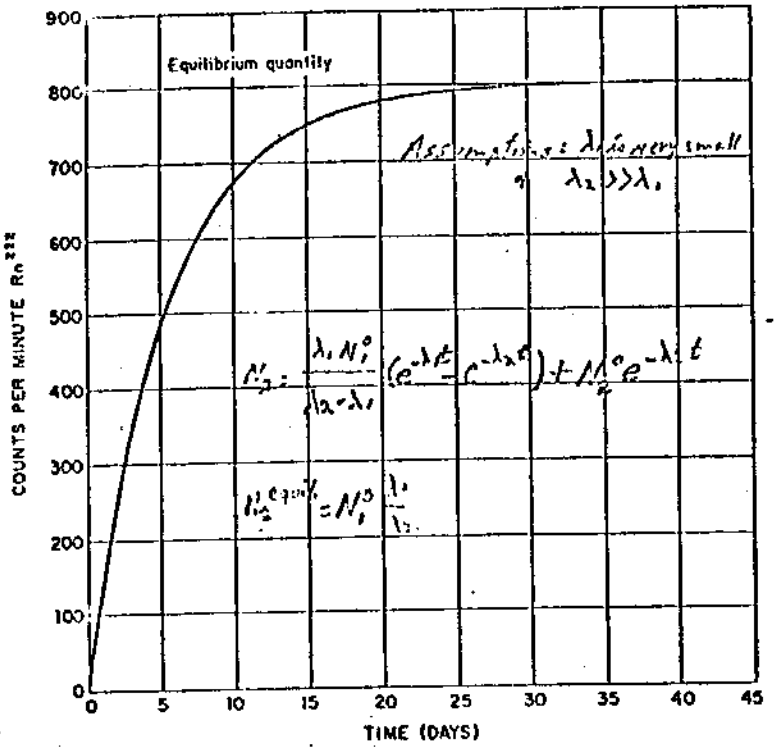


Fig. 2.5. Growth of daughter from long-lived parent

Equations similar to (2.8) may be derived for the growth and decay of the third or later members of a decay sequence. The general solution for the number of nuclei of the nth product at time t, N_n, is

$$N_n = C_1 e^{-\lambda_1 t} + C_2 e^{-\lambda_2 t} + C_3 e^{-\lambda_3 t} + \cdots C_n e^{-\lambda_n t} \qquad (2.11)$$

where

$$C_1 = \frac{\lambda_1\lambda_2\lambda_3\cdots\lambda_{n-1}N_1^0}{(\lambda_2-\lambda_1)(\lambda_3-\lambda_1)\cdots(\lambda_n-\lambda_1)}$$

$$C_2 = \frac{\lambda_1\lambda_2\lambda_3\cdots\lambda_{n-1}N_1^0}{(\lambda_1-\lambda_2)(\lambda_3-\lambda_2)\cdots(\lambda_n-\lambda_2)}$$

$$C_3 = \frac{\lambda_1\lambda_2\lambda_3\cdots\lambda_{n-1}N_1^0}{(\lambda_1-\lambda_3)(\lambda_2-\lambda_3)(\lambda_4-\lambda_3)\cdots(\lambda_n-\lambda_3)}$$

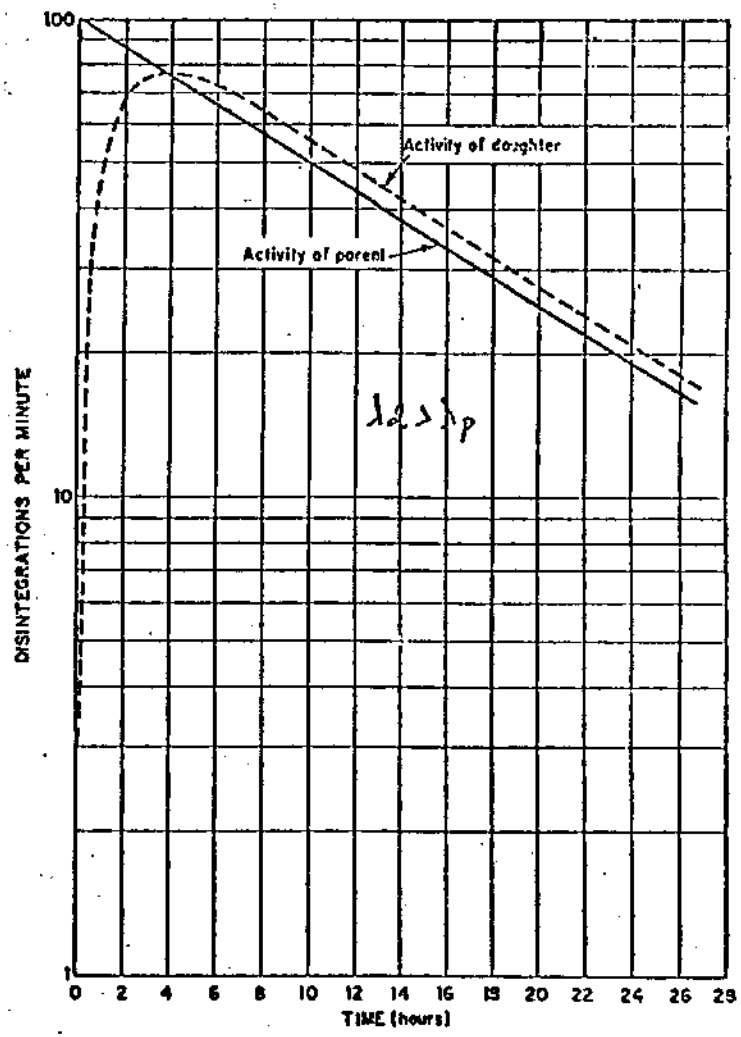


Fig. 2.6. Growth and decay of daughter in transient equilibrium with parent

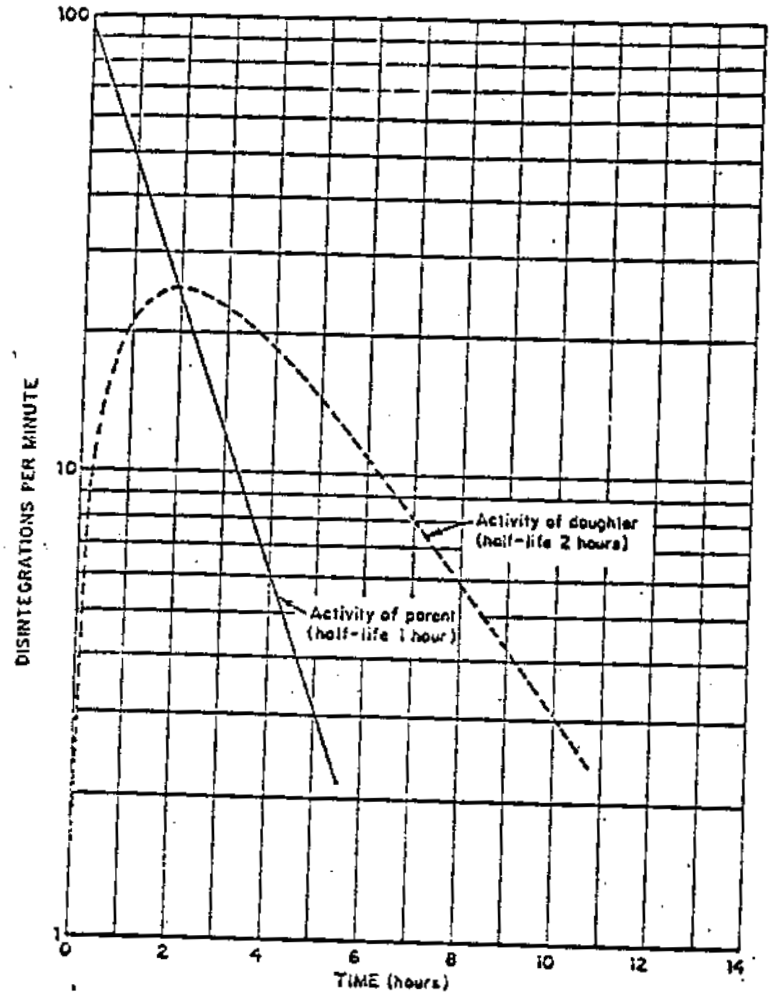


Fig. 2.7. Growth and decay of daughter from short-lived parent

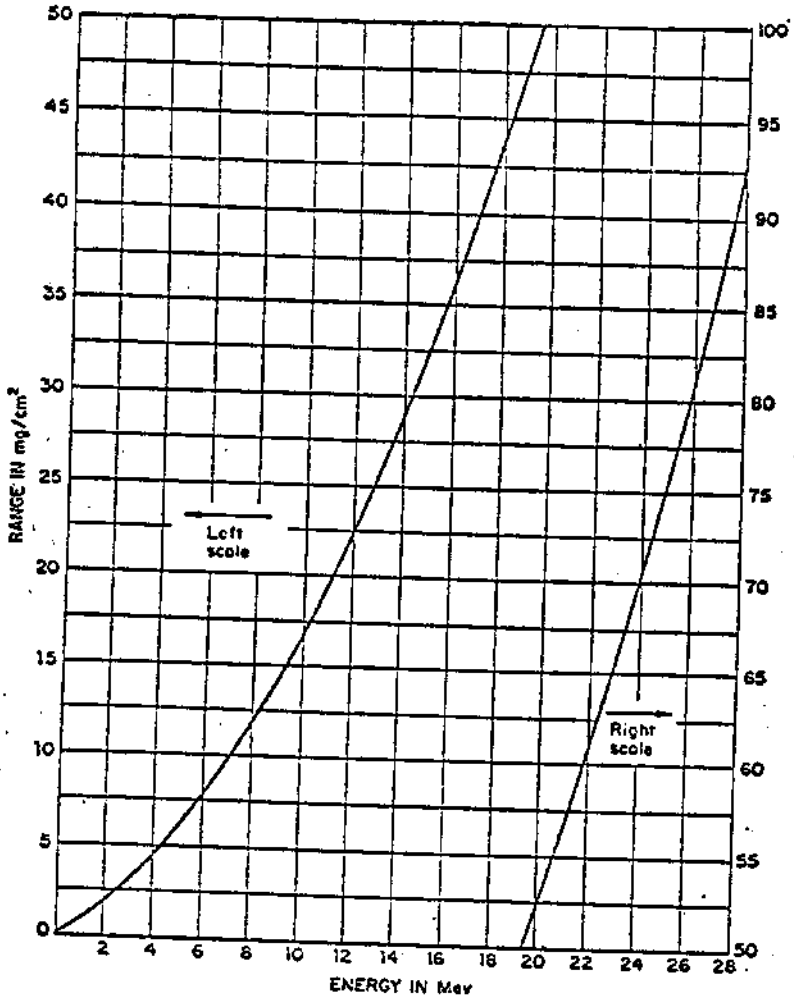


Fig. 11.3(b). Range-energy curves for helium ions in aluminum metal, calculated from proton ranges by H. E. Conzett.

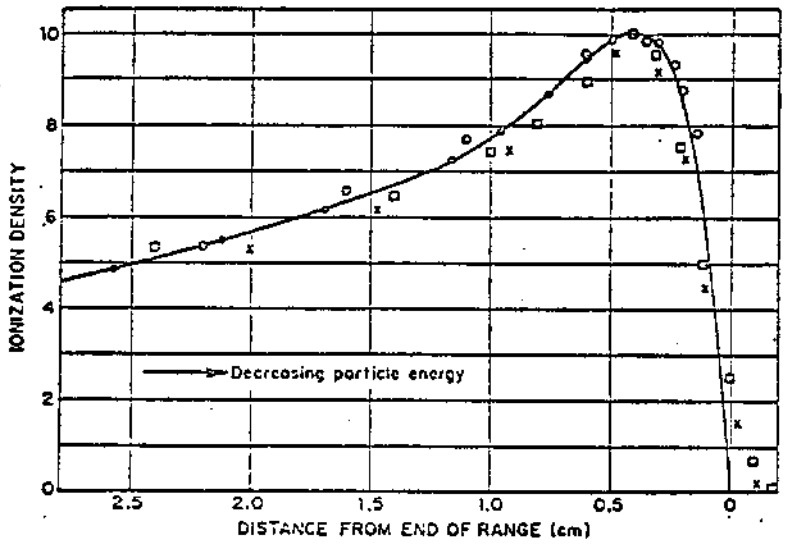
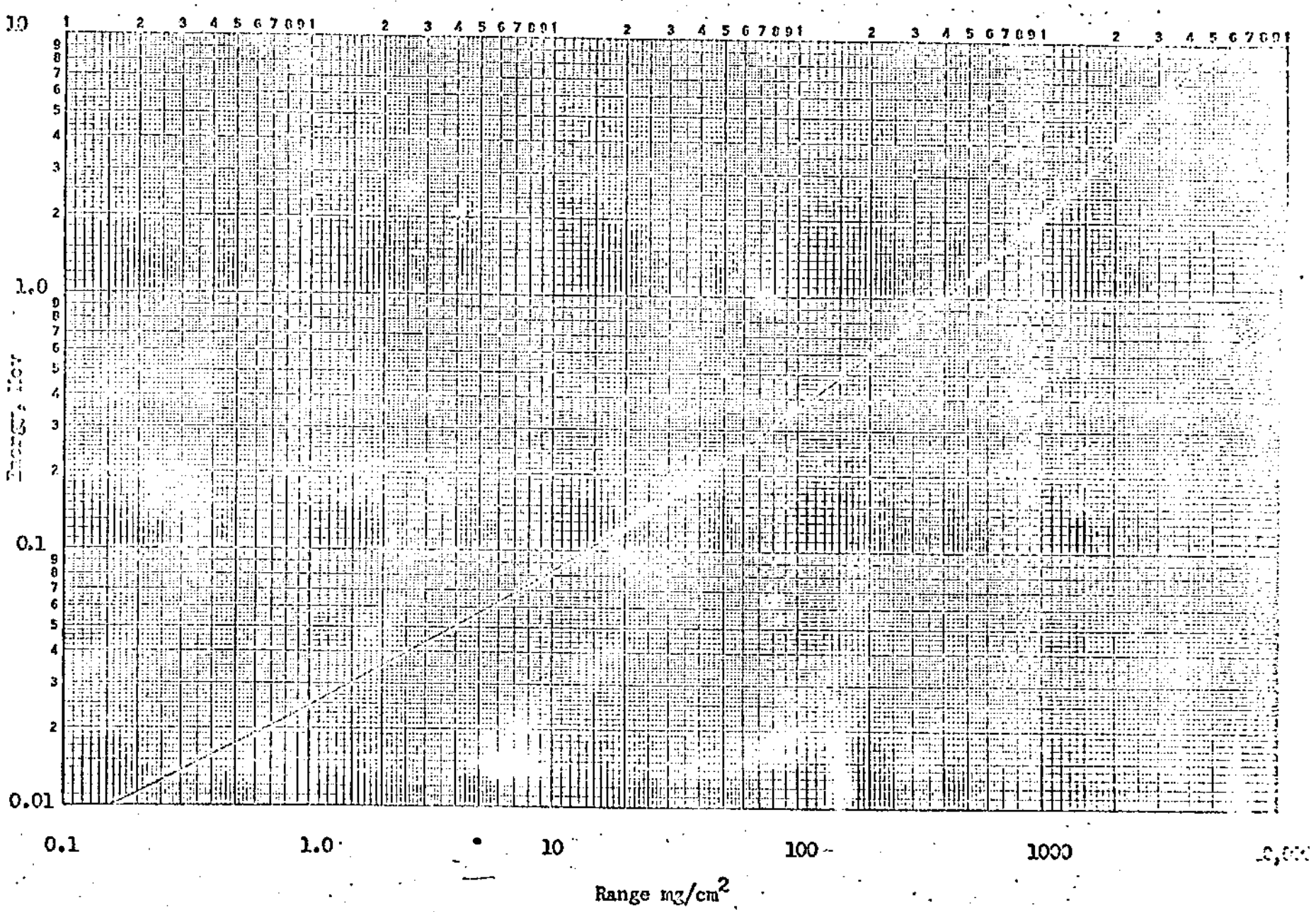


Fig. 11.1. Ionization density along the path of an α-particle moving in air (the Bragg curve). M. G. Holloway and M. S. Livingston, *Phys. Rev.*, 54, 29 (1938)

1260894

BETA PARTICLE

RANGE ENERGY CURVE



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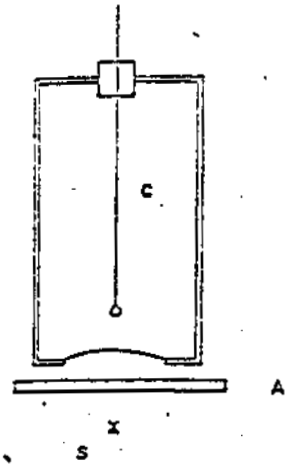


Fig. 11.7. Schematic picture of source, absorber and counter arrangement for measuring absorption curve for a β-emitter. C is the counter, A the absorber and S the source

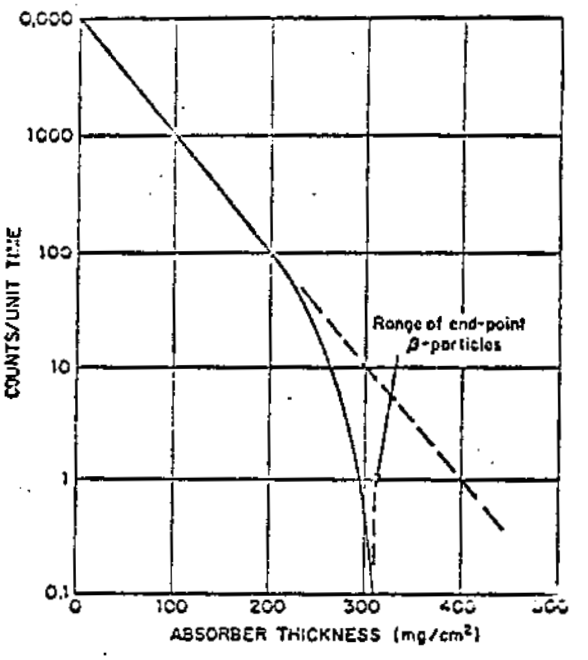


Fig. 11.8. Schematic absorption curve for a continuous β-spectrum of end point 310 mg/cm²

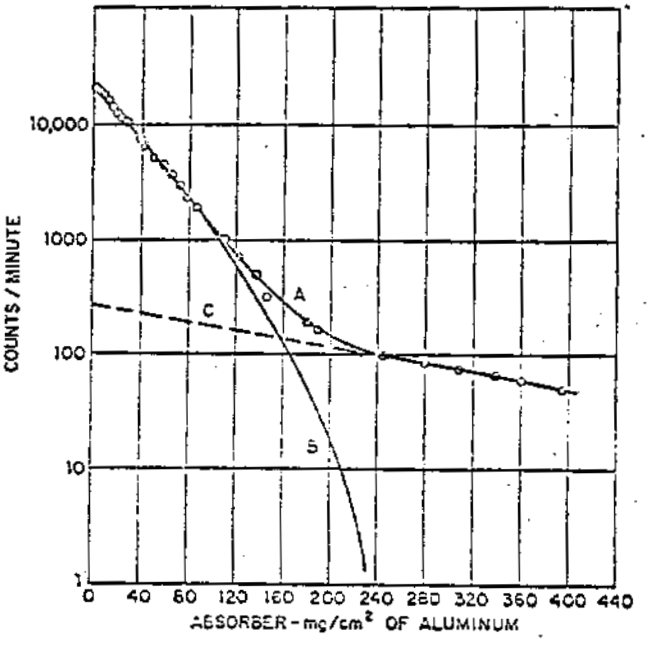


Fig. 11.9. Aluminum absorption curve for β^--particles from Am^{242}. A: Experimental curve, C: Component due to [illegible] B: (Curve A minus curve C). Curve B is due to [illegible] particles alone. J. M. Grunlund, B. C. Harvey, N. Moss and [illegible] Yaffe, *Phys. Rev.*, 78, 69 (1950)

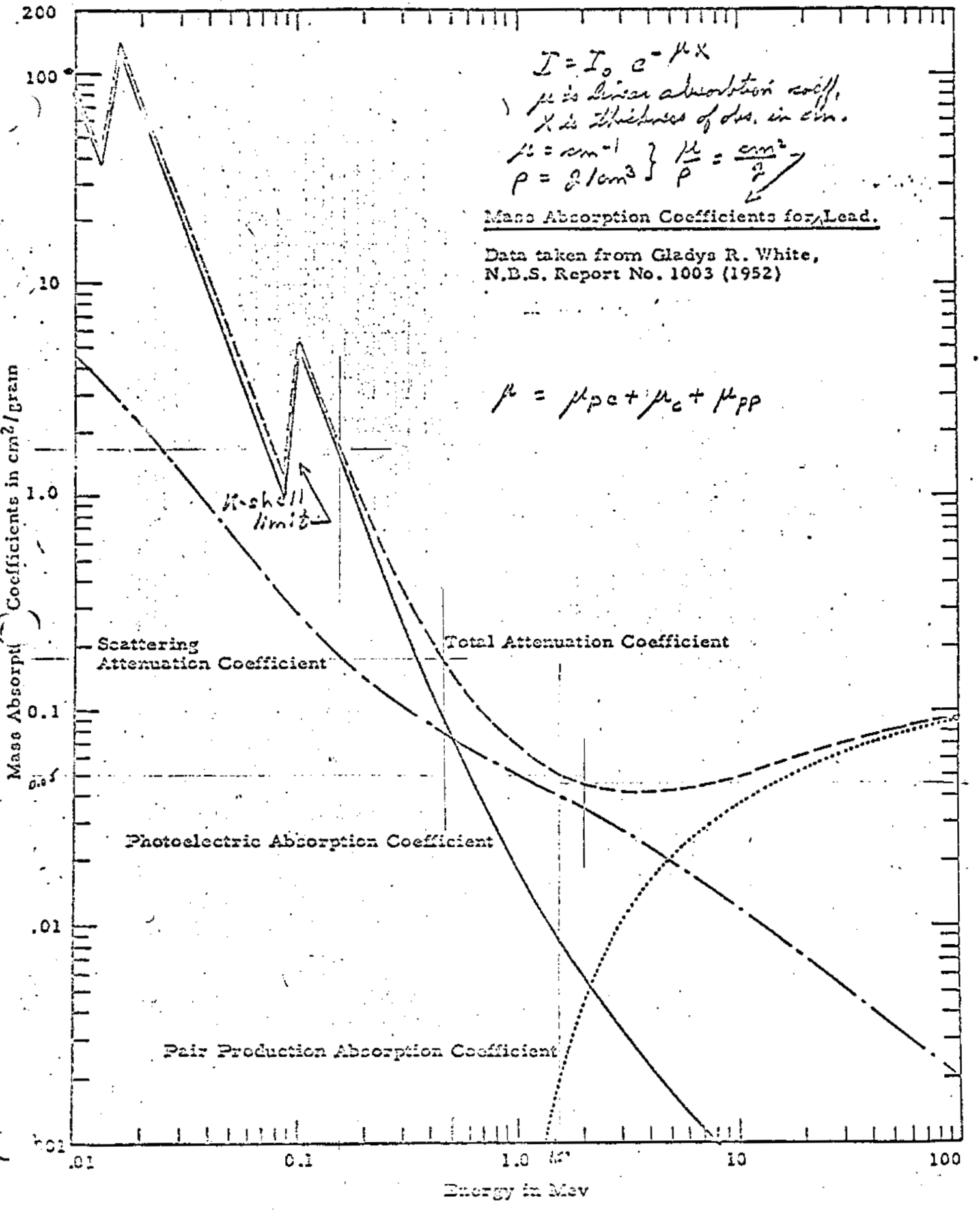

$I = I_0 e^{-\mu x}$
μ is linear absorption coeff.
x is thickness of abs. in cm.
$\mu = cm^{-1}$
$\rho = g/cm^3$
$\frac{\mu}{\rho} = \frac{cm^2}{g}$
Mass Absorption Coefficients for Lead.
Data taken from Gladys R. White, N.B.S. Report No. 1003 (1952)
$\mu = \mu_{pe} + \mu_c + \mu_{pp}$
K-shell limit
Scattering Attenuation Coefficient
Total Attenuation Coefficient
Photoelectric Absorption Coefficient
Pair Production Absorption Coefficient
Mass Absorption Coefficients in cm²/gram
Energy in Mev
200
100
10
1.0
0.1
.01
.001
.01
0.1
1.0
10
100

TABLE 12.1

COMPARISON OF THE VARIOUS TYPES OF COUNTERS

Type of counter	Resolving Time	Typical energy resolution	Commonest applications
Grid ion chamber	10 μsec	0.4% (α's)	Measurement α-particle energies.
Proportional counter	1 μsec	∿ 1% (charged particles)	1. Measurement particle energies. 2. Detection of radiation, no energy measurement involved. 3. Measurement energies very low energy γ-rays and X-rays.
Geiger counters	∿ 1 msec	None	1. Portable instruments for prospecting, fall-out detections, etc. 2. For economy where large numbers of detectors required, e.g. in cosmic ray experiments.
NaI (Tl) scintillation counters	1 μsec	1% (charged particles), 8% (γ-rays, 1 Mev)	1. Detection and energy measurement of γ-rays. 2. Detection and energy measurement of charged particles.
Organic scintillation counters	1 μsec 10^{-8}-10^{-9} sec	10% (electrons) 15% (heavy charged particles, e.g. He^4).	1. Electron energy measurements. 2. Detection charged particles where high speed of response required.
Solid state counters	0.1-1 μsec 10^{-8} sec	0.2% (charged particles ?	1. Energy measurements for charged particles. 2. Detection of charged particles when no energy measurement is required.

energy resolution figures are only typical, wide variations may occur in particular applications.

CARBON-14

Mount: 1 1/2 inch stainless steel dish on shelf 1

Precipitate: Barium Carbonate

Data from: Treibs (1958)

Infinite thickness counting begins at approximately 100 mg on 1 1/2" dish. Above 100 mg on dish, (counts) (0.150) (milligrams on dish) = disintegrations.

Counter Correction Factors

mg ppt. on dish	dis./ count	mg ppt. on dish	dis./ count
0	5.00	56	9.71
2	4.90	58	9.90
4	4.88	60	10.2
6	4.88	62	10.4
8	4.92	64	10.6
10	5.00	66	10.9
12	5.21	68	11.1
14	5.41	70	11.4
16	5.62	72	11.6
18	5.81	74	11.8
20	6.06	76	12.0
22	6.33	78	12.3
24	6.45	80	12.6
26	6.67	82	12.8
28	6.85	84	13.0
30	7.09	86	13.3
32	7.24	88	13.6
34	7.46	90	13.9
36	7.69	92	14.2
38	7.87	94	14.5
40	8.00	96	14.7
42	8.20	98	14.9
44	8.33	100	15.0
46	8.55		
48	8.85		
50	9.09		
52	9.25		
54	9.52		

Above 100 mg on dish, assume mount is infinitely thick. Then (counts) (0.150) (mg) = disintegrations.

1260899

PHOSPHORUS-32

Mounts: 1' stainless steel dish on shelf 1

Precipitate: Ammonium Molybdiphosphate

Data From: Treibs, (1958)

mg ppt. on mount	dis./ count	mg ppt. on mount	dis./ count
0	1.739	105	1.968
5	1.748	110	1.976
10	1.757	115	1.99
15	1.767	120	2.00
20	1.779	125	2.01
25	1.792	130	2.02
30	1.802	135	2.03
35	1.815	140	2.04
40	1.825	145	2.05
45	1.835	150	2.06
50	1.845	155	2.07
55	1.855	160	2.08
60	1.865	165	2.09
65	1.876	170	2.10
70	1.887	175	2.11
75	1.898	180	2.12
80	1.912	185	2.13
85	1.923	190	2.14
90	1.934	195	2.15
95	1.945	200	2.15
100	1.953		

RUTHENIUM - 103

Mount: Millipore filter with nutrient pad on shelf 2

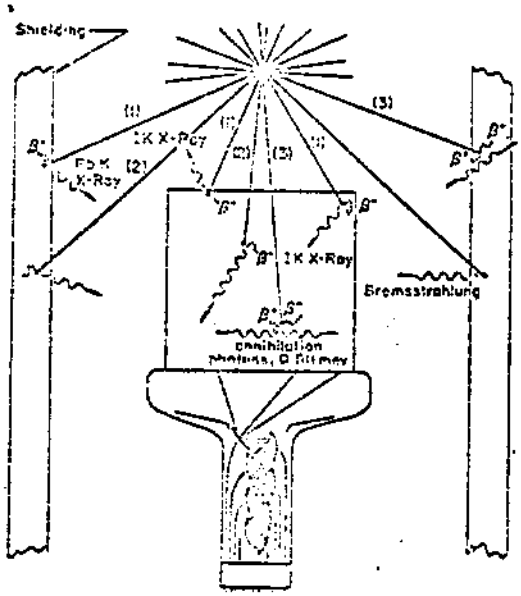
Precipitate: Hydrous ruthenium dioxide

Data from: D.M. Robertson, H.A. Treibs (1958 - 1959)

Notes:
1. Interposition of 352 or 220 mg/cm^2 aluminum between detector and sample reduces the counting rate due to Ru-103 to less than 1% of the original value.
2. The following table is based on counting measurements made on Ru-103 - Rh-103 equilibrium mixture. However, the disintegration rates obtained by the application of this table are for Ru-103 only, as is customary.

Counter Correction Factors

mg ppt. on mount	dis./ count	mg ppt. on mount	dis./ count
5	11.2	21	15.8
6	11.5	22	16.0
7	11.9	23	16.2
8	12.2	24	16.5
9	12.5	25	16.7
10	12.8	26	16.9
11	13.1	27	17.0
12	13.5	28	17.2
13	13.7	29	17.4
14	14.0	30	17.6
15	14.3	32	17.9
16	14.6	34	18.2
17	14.8	36	18.6
18	15.0	38	18.9
19	15.2	40	19.2
20	15.5		



(1) Photoelectric interaction
(2) Compton interaction
(3) Pair Production

FIG. 3-4. Schematic picture of the primary interactions which affect the response curves of a sodium-iodide scintillation crystal.

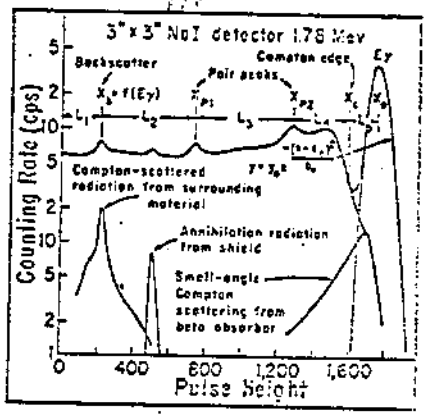


FIG. 2. ANALYTIC MODEL of detector response to single gamma illustrating detailed features of pulse-height spectrum

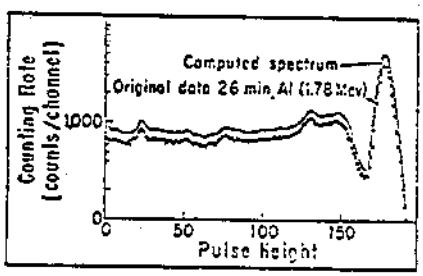


FIG. 3. COMPARISON of computed response and experimental pulse-height distribution for 1.78-Mev gamma. Curves are displaced vertically for comparison

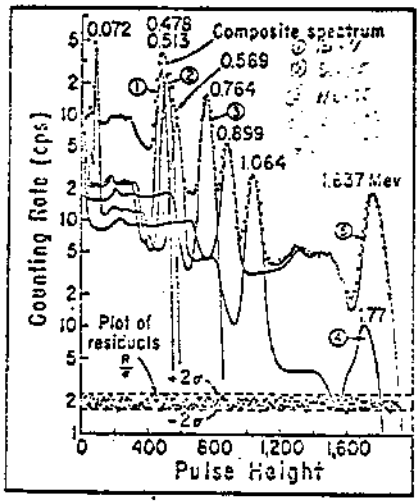
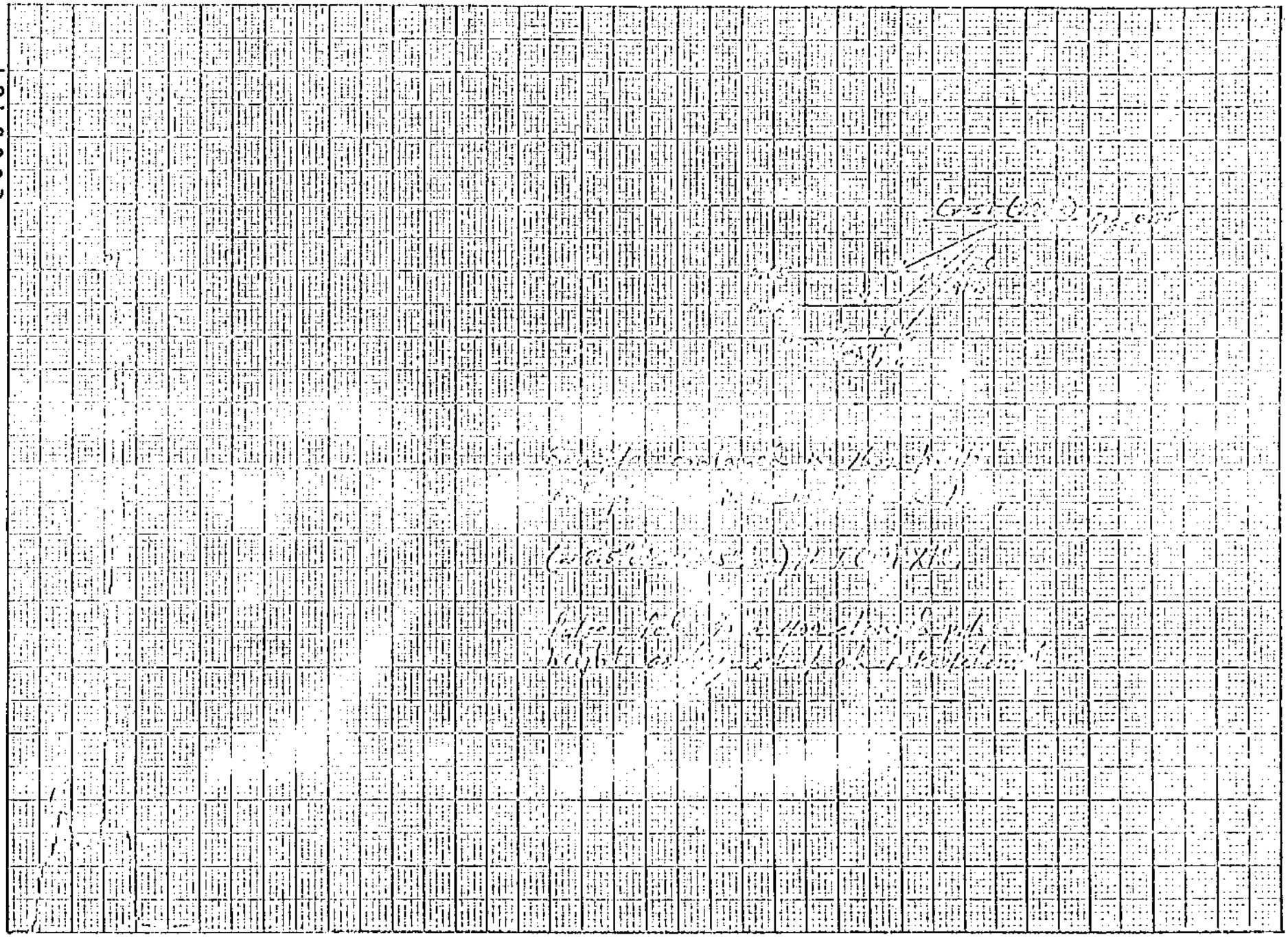
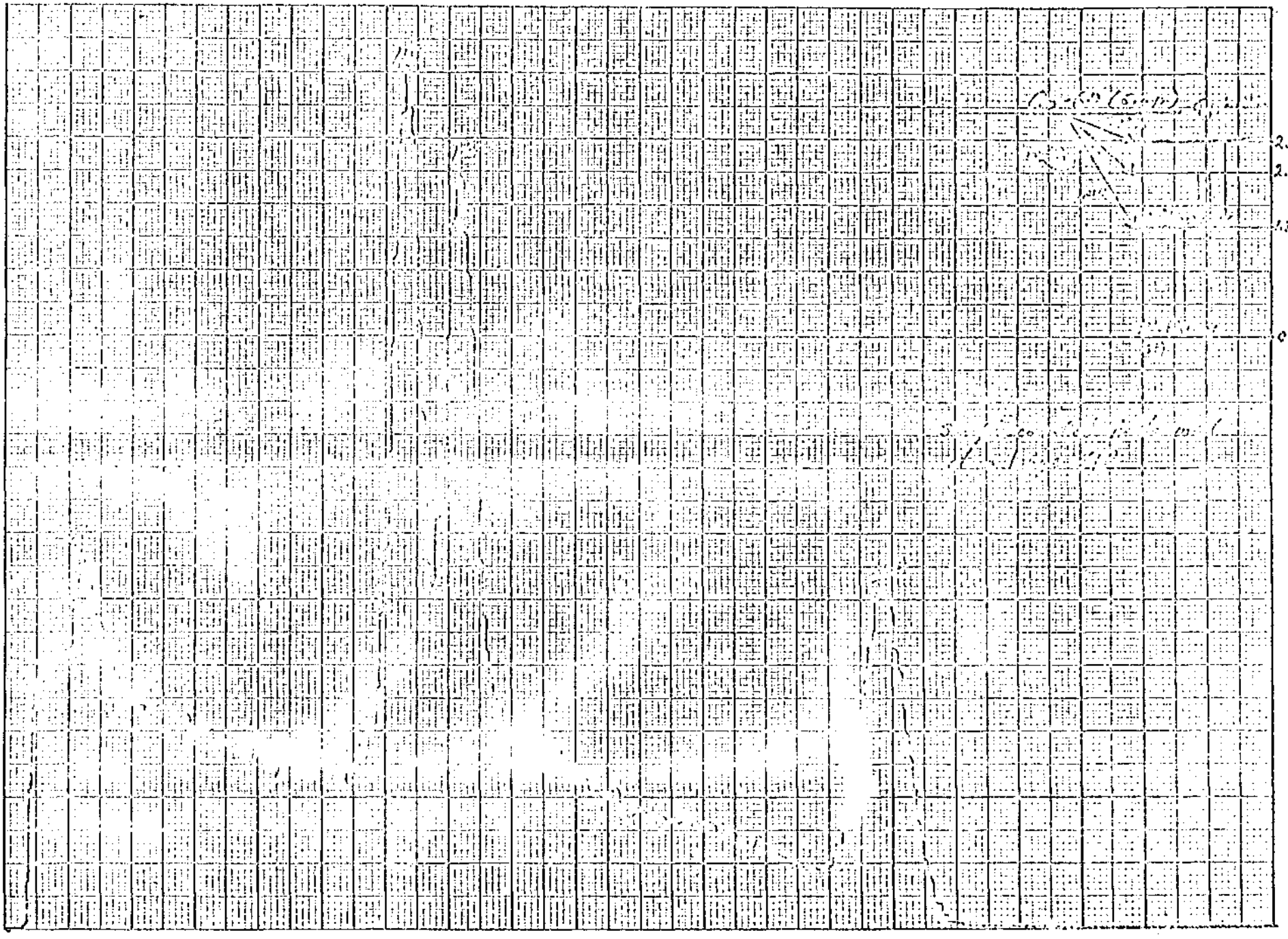


FIG. 4. LEAST-SQUARES ANALYSIS of five-component spectrum with 10 gammas. Component distributions (circled numbers) were measured separately and then in combination. Calculated component intensities agreed to within 1% of actual intensities



Scale 2K
Chords 0-359



Scale 50K

10 X 10 TO THE ½ INCH
KEUFFEL & ESSER CO.
353-11
MADE IN U.S.A.

1260905

400 CHANNEL ANALYZER CALIBRATIONS 9 OZ. JAR

Cs^{137} IN CHANNEL # 664

Crystal No. 1 (1113)
Serial No. U-497

(COMPTON + INTERFERENCE CORRECTIONS)

(ISOTOPE)	CHANNELS	Ba-La^{140} 155-165	K^{40} 141-151	Zn^{65} 107-117	Zr-Nb^{95}* 71-80	Cs^{137} 63-70	Ru^{106} 59-65	Ru^{106} 46-54	Ru^{103} 46-54	I^{131} 34-38	Cr^{51} 30-33	Ce-Pr^{144}** 11-16	Ce^{141} 11-16	Ce-Pr^{144}* 7-9
Ba-La^{140}	155-165	1.0	0.1074	0.0002	0.0002	0.0		0.0052	0.0	0.0	0.0	0.0029	0.0	0.0062
K^{40}	141-151	0.2218	1.0	0.0011	0.0014	0.0004		0.0038	0.0	0.0001	0.0012	0.0081	0.0002	0.0182
Zn^{65}	107-117	0.4118	0.3887	1.0	0.0007	0.0001		0.0459	0.0	0.0	0.0	0.0049	0.0	0.0109
Zr-Nb^{95}	71-80	0.7616	0.2887	0.3154	1.0	0.0377	0.1362	0.0476	0.0002	0.0110	0.0	0.0161	0.0	0.0362
Cs^{137}	63-70	0.4440	0.2287	0.2385	0.1658	1.0	0.5934	0.2077	0.0166	0.0480	0.0002	0.0267	0.0001	0.0599
Ru^{106}	59-65				0.1036		1.0		0.0448			0.0102	0.0	0.0230
Ru^{106}	46-54	2.873	0.2954	0.4108	0.3011	0.1693	2.858	1.0	1.0	0.0170	0.0022	0.0146	0.0001	0.0328
Ru^{103}	46-54	2.873	0.2954	0.4108	0.3011	0.1693	2.858	1.0	1.0	0.0170	0.0022	0.0146	0.0001	0.0328
I^{131}	34-38	0.9495	0.2356	0.2143	0.2027	0.1975	0.5577	0.1952	0.1060	1.0	0.1674	0.0180	0.0	0.0405
Cr^{51}	30-33	1.521	0.2177	0.1975	0.1854	0.1697		0.2130	0.1272	0.2654	1.0	0.0182	0.0003	0.0409
Ce-Pr^{144}	11-16	2.427	0.7208	0.3170	0.4419	0.2967	1.397	0.4890	0.2725	0.3630	0.3722	1.0	1.0	2.243
Ce^{141}	11-16	2.427	0.7208	0.3170	0.4419	0.2967	1.397	0.4890	0.2725	0.3630	0.3722	1.0	1.0	2.243
Ce-Pr^{144}	7-9				0.1732	0.1068	0.6560		0.0962	0.1248		0.4458	0.1737	1.0
DPM/CPM		260.6	1072.7	161.4	63.4	61.48	393.3	137.8	32.65	38.58	294.04	221.4	26.92	496.7

* Zr-Nb^{95} = 1: 2.117 Prepared by mixing calibrated Zr^{95} and Nb^{95} (MRW - 8-5-60) Recalibrated 7-20-60 WY

** Data for Ce-Pr^{144} (11-16) and Ce-Pr^{144} (7-9) from recalibration of 11-18-60 (MRW - 1-25-61)

Characteristic data for each isotope is tabulated vertically.
D/C factors include a 6% increase due to sample changer installation except where calibration was made subsequent to installation.

Data of W. Y. Matsumoto 8-26-59
Revised by M. R. Weiler 1-25-61
Checked by L. Kellogg 2-3-61

- 24 -

1260906

LHS Dishes and Jars corrected
for Sample Changer 1/8" linoleum.
See Note, pg. 3.

DISINTEGRATIONS PER COUNT

RCAO 400-CHANNEL GAMMA ENERGY ANALYZER

ISOTOPE	CHANNELS	*** DISHES LHS	*** DISHES RHS	VIALS LHS	VIALS RHS	*** JARS LHS	*** JARS RHS	
Ru^{106}	46-54	43.99	40.65	19.80	19.00	137.80	131.00	(8)
Ru^{106}	59-65	124.05	112.60	56.18	51.48	393.10	357.00	(9)
Ag^{110}	85-94	25.48	23.92	16.21	16.37	75.86	71.57	(9)
Sb^{124}	57-64	13.40	12.36	6.47	6.09	42.51	38.95	(5)
Sb^{124}	164-176	79.57	69.29	39.08	35.64	245.43	215.76	(5)
Sb^{125}	40-46	24.49	22.60	9.84	10.06	86.23	79.18	(5)
Sb^{125}	57-64	44.33	41.03	18.05	18.87	154.04	144.60	(5)
I^{131}	34-38	10.62	9.42	3.54	3.20	38.58	35.50	(1)
* ^{133}	50-56	14.67	13.07	4.70	4.44	46.84	42.50	(13)
$Te-I^{132}$	20-25	7.95	7.47	3.57	3.76	25.33	24.46	(5')
Ba^{133}	5-9	16.83	18.65	11.20	10.61			(11)
Ba^{133}	32-39	11.62	10.89	5.28	5.42			(11)
** Ba^{140}	51-57	55.81	46.40	19.29	17.16	169.66	160.63	---
Cs^{137}	63-70	17.57	15.80	6.78	6.46	61.48	55.70	(2)
La^{140}	155-165	47.28	39.50	26.00	23.20	132.82	117.00	(5)
$Ba-La^{140}$	155-165	89.89	78.80	48.40	44.40	260.55	221.00	(5)
Ce^{141}	11-16	7.93	7.94	2.84	2.83	26.92	28.80	(5)
Ce^{143}	28-31	21.90	17.10	11.02	10.26			(13)
$Ce-Pr^{144}$	7-9	213.97	281.30	96.98	91.35			(5)
$Ce-Pr^{144}$	11-16	66.29	66.90	25.75	24.56	257.58	259.00	(5)
Eu^{152}	94-99	156.03	132.30	56.30	52.40			(5')
Sm^{153}	9-11	15.69	16.28	6.28	5.41			(5)
U^{239}	8-12	6.69	7.06	3.54	3.40	19.57	21.40	(5)

*Data after correction for 7% I^{131} contamination in counted sources.
No correction made for I^{135} contamination.
**Calculated from $Ba^{140}-La^{140}$ and La^{140} data.
***See page 3.

RADIOACTIVE WASTE MANAGEMENT

Purpose

1. Control of Radiation Exposure
    a. On plant personnel
    b. Off plant personnel
2. Store quantities of radionuclides in retrievable locations

Types of Radioactive Waste

1. Gaseous waste
    a. Suspended radioactive particles
    b. Radioactive gases
2. Liquid waste
    a. Aqueous
        (1) Reactor coolant and decontamination streams
        (2) Fuel element processing waste
    b. Organic
3. Solid wastes

Disposal Concepts

1. Concentrate and contain
2. Dilute and Disperse
3. Combination of 1 and 2

Gaseous Waste Treatment and Control

1. Normal gaseous effluent associated with HAPO facilities
    a. Control of radioactive gases
        (1) Fuel element "cooling"
        (2) Absorption of halides and noble gases
        (3) Chemical treatment
    b. Control of radioactive particulates
2. Measurement requirements
    a. Continuous measurement
    b. Continuous sampling
    c. Analyses for specific radionuclides
3. Accidental release control methods
    a. Containment
    b. Confinement

Liquid Waste Treatment and Control

1. Types of liquid waste
    a. Reactor coolant water
        (1) Normal
        (2) With fuel element rupture(s)
    b. Reactor decontamination solutions
    c. Laboratory solutions
    d. Fuel element processing waste
        (1) High level waste (>100 uc/cc)
            (a) Coating waste and other non-boiling waste storage
            (b) Bioling waste storage (cooled tanks)
            (c) In tank solidification
            (d) CPD waste management program

(2) Intermediate level waste (>100 uc/cc 75 x 10^{-5} uc/cc)

(a) Soil retention

(b) Cribs and caverns

(3) Low level waste (>5 x 10^{-5} uc/cc)

e. Organic wastes

2. Concentration methods

a. Evaporation (decontamination factor 10^4 - 10^7)

b. Ion exchange

3. Measurement methods

a. Sampling

(1) Continuous

(2) Batchwise

(3) Periodic

b. Continuous measurement

c. Well sampling and monitoring

4. Tritium

5. Transportation of waste

6. Accidents involving liquid wastes

7. Control of disposal areas

Solid Waste Treatment and Dispsoal

1. Types of solid waste

a. Low level waste

b. Waste containing toxic materials (dose rates do no prohibit handling)

c. Waste with high radiation dose rates (remote handling methods required)

2. Disposal methods
    a. Burial trenches
    b. Tunnels
    c. Dry wells
    d. Other
3. Volume reduction methods
    a. Incineration
    b. Compaction
4. Transportation of waste
5. Accidents
6. Control of disposal areas

Lee Brown – Criticality

44-64/668

INFORMATION ON NUCLEAR EXCURSIONS THAT HAVE OCCURRED IN INDUSTRY

	Y-12	LA	IF-I	IF-II	RECUPLEX	Ri
DATE	June 16, 1958 2:05 P.M. Mon	Dec. 30, 1958 Tues	Oct 16, 1959 Friday	Jan 25, 1961 Wed	Apr 7, 1962 Sat.	7/24/6.. Fri..
TIME	2:05 P.M.	4:35 P.M.	2:50 A.M.	9:50 A.M.	10:59 A.M.	6:0..
ROUTINE OPERATION ?	FY Inventory No	Year End Inventory	Routine	Not Routine	No	Ye..
FISSILE MATERIAL	2.1 KG U^{235}	Low Level Waste	UH	UnH	Plu Nitrate	UO2F..
AMOUNT	5×10^{-16} fissions	3.3 Kg	34.5 Kg.	8 Kg	1.4 Kg	
CONCENTRATION	38 g/l	20 g/l	45 g/l	22 g/l	37 g/l	
VESSEL DIAMETER	22"	30"	9'	24"	17.4"	18"
VESSEL VOLUME	55 gal	225 gal	5000 gal.	94 gal.	17 gal.	27 g..
PROMPT NO. OF FISSIONS	5×10^{-16} fissions	Thickness layer 8" 1.5×10^{17} fissions	1×10^{17}	6×10^{17}	5×10^{16}	1.2x10..
DURATION OF EXCURSION		less than a second	20 min	< 1 sec.	37½ hrs.	90 min..
TOTAL NO. OF FISSIONS	13×10^{17}	1.5×10^{17} fissions	4×10^{19}		8.7×10^{17}	
SHIELDED FACILITY ?	No		Yes	Yes	No	No
QUENCH	Dilution	Dilution with water	Concentration	Change in geometry	Concentration	Gam..
PROPERTY DAMAGE	None	None	None	None	None	Min..
PERSONNEL EXPOSED	Eight 430 rem 341 87 428 87 410 29 [illegible]	Three 12,000 rem 135 " 72 "	None	None	3 For 12 [illegible] 45-65 10-30	3
CAUSE	Poor Design Administrative control	Failure to follow procedure	Poor Design	Poor Communication		

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TABLE I

SITES OF CRITICALITY INCIDENTS

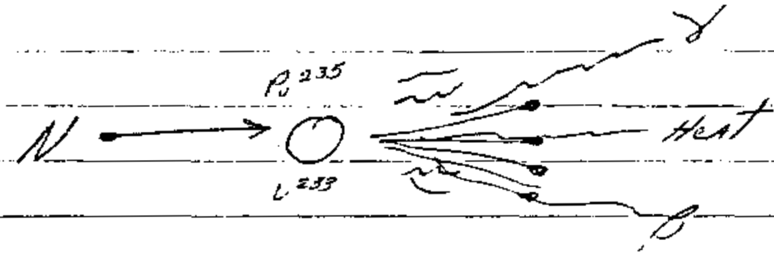
(Reactor Incidents not Included)

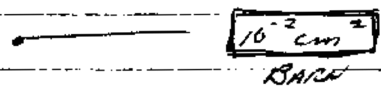
	LASL	ORNL	HAPO	IF	FOREIGN	UCRL	UN
1945	XXX (1)						
1946	X (1)						
1947							
1948							
1949	X						
1950							
1951	X						
1952	X		X				
1953							
1954	X	X			(X)		
1955							
1956	X	X					
1957	X						
1958	⊠	⊠					
1959					X		
1960				⊠			
1961		X					
1962				⊠			
1963			⊠				
1964						X	
							⊠

X - Critical Mass Laboratory
⊠ - Industrial Plant
(X)- Facility not known

Energy Release Per Fission — MEV

	MEV	
Kinetic Energy of Fission Fragments	167 ± 5	87%
Prompt gamma rays	6 ± 1	5%
Kinetic Energy of Fission Neutrons	5	
Fission Product Decay		
Gamma	6 ± 1	7%
Beta	8 ± 15	
Neutrinos	12	
	204 ± 7	





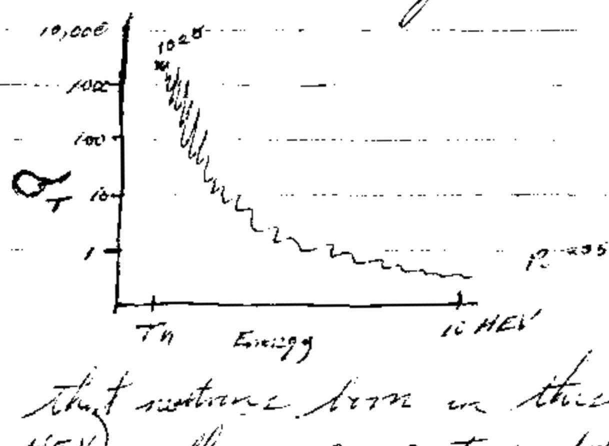
What can happen to neutron. — Cross sections

1. Fission — σ_F } σ_C
2. absorbed and lost — σ_A
3. Inelastic scattering — σ_{In} } σ_S
4. Elastic scattering — σ_E

σ_T

Thermal ← Reduces Neutron Energy — 3.

H Hydrogen, C Carbon, D Deuterium, Be Berillium } Moderators — 4.



What is prob that neutrons born in this system and born fast (1-2 MEV) will escape capture by the 238.

P = (Resonance escape prob)

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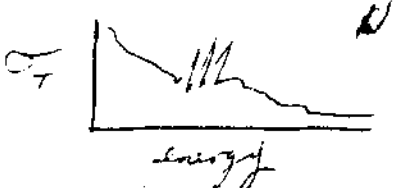

What is prob. of escape from capture in U^{238} – P Resonance Escape

What is prob. of fission in U^{238} ——— ϵ

What is prob of absorption of neutron in fuel — f

How many neutrons are going to be born for = η
that captured

$$\eta f \epsilon p = k_\infty$$

What is prob that fast neutron will not escape from the system = $e^{-B^2\tau}$ ← geometry ← distance

What is prob that thermal neutron will not escape = $\frac{1}{1+L^2B^2}$

$$\frac{(\eta f \epsilon p) e^{-B^2\tau}}{1+L^2B^2} = k_{effective}$$

Say we have 100 thermal neutrons in system

Say we get 20 back

$\frac{20}{180}$ Say 20 captured by U^{238}

$\frac{40}{140}$ Lost do to leakage

$\frac{30}{110}$ How many thermal lost out
110 neutrons available for fission

$\frac{10}{100}$ captured by fuel
left for fission.

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$$k = \frac{\text{No. of N. in gen 2}}{\text{No. of N. in gen 2}} = \frac{100}{100} = 1$$

For $k = 1$ the system is just critical
$k < 1$ system is subcritical and will die out
$k > 1$ system is super critical

What necessary
1. Critical mass
2. Slow neutrons

Factor

Moderator
Pu metal → 5.6 Kg
Solution → .52 Kg

Reflector
Bare Pu ⇒ 10 Kg 52 700 g
Ref Pu = 5.6 Kg 72 500 g

Shape (How does it affect escape of neutrons - depends on surface volume ratio)
Optimum shape is a sphere

Neutron Absorber

Good line for critical mass

	U^{235}	H_2O or Ni Pu ^{240}	Pu
Minimum Critical Mass	sol'n: 820 g / metal: 52 Kg	< 10 g/l	520 g / 5.6 Kg	8.0 g/l

Dry metal
< 5% U^{235} unpacked
Can not be made critical

solution < 10% U^{235} cannot be made critical

Ride < .77% U^{238} in H_2O

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Hazard Analysis - Watson

I Inventory

A. Special facilities - Isolated Radionuclides

1. Shipping
2. Laboratory
    a. Non-fissile
    b. Fissile

B Chemical Separations - Irradiated Fuels

1. Product Stream
2. Waste Handling Streams
3. Recovery and Storage Facilities

C. Reactor

1. Type
2. Fuel loading
3. Power level
4. Time of Irradiation

II Fraction of Inventory Released

A. Experimental Data

1. Uranium Fuel Elements
2. Co^{++} & Sr^{++} - $SrCO_3$

B. Mechanisms of Release

1. Burning of Fuel (or Radioactive Material)
2. [illegible]
3. Melting of metal
4. Chemical Reaction with [illegible]

C. Spent and Irradiated Fuel Elements

1. [illegible]
2. Categorization of F.P.
3. [illegible]

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III Fraction Escaping Containment
A. Plate-out
B. Fire Spray
C. Filters
D. Collectors

IV Rate of Release
A. Radio active decay
B. Wind Variability

ATMOS. DISPERSION CALCULATION

I Mathematical Models
A. General Model, Inst. Pt. Source

$$\chi_{(x,y,z,t)} = \frac{Q'}{2\pi^{3/2}\sigma_x\sigma_y\sigma_z} e^{-1/2\left[\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2}\right]}$$

B. Continuous Pt. Source
1. Unreflected

$$\chi_{(x,y,z)} = \frac{Q'}{2\pi\sigma_y\sigma_z\bar{u}} e^{-1/2\left[\frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2}\right]}$$

3. At Ground Level

$$\chi = \frac{Q'}{\pi\sigma_y\sigma_z\bar{u}} e^{-\left[\frac{y^2}{2\sigma_y^2} + \frac{h^2}{2\sigma_z^2}\right]}$$

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4. Time Integrated + Normalized

$$E = \frac{2}{\pi \sigma_y \sigma_z \bar{u}_A} e^{-\frac{y^2}{2\sigma_y^2}} e^{-\frac{h^2}{2\sigma_z^2}}$$

$$\left(\frac{E}{Q}\right) = \left[\frac{1}{\pi \sigma_y \sigma_z \bar{u}_h}\right]\left[e^{-\frac{y^2}{2\sigma_y^2}}\right]\left[e^{-\frac{h^2}{2\sigma_z^2}}\right]$$

$$\left(\frac{E}{Q}\right) = \left(\frac{E}{Q}\right)_{\phi} e^{\frac{-y^2}{2\sigma_y^2}}$$

5. Sutton Equations

$$\sigma_y^2 = \tfrac{1}{2} C_y^2 x^{(2-n)}$$

$$\sigma_z^2 = \tfrac{1}{2} C_z^2 x^{(2-n)}$$

Dependent on: 1. Wind speed
2. Ground roughness or stability
3. Distance downwind

6. "Modified" Diffusion Functions

$$\left(\frac{E}{Q}\right) = \frac{1}{\pi \sigma_y \sigma_z \bar{u}_h} e^{-\left[\frac{y^2}{2\sigma_y^2} + \frac{h^2}{2\sigma_z^2}\right]}$$

$$\sigma_z^2 = a(1 - e^{-b t^{-d}}) + c t$$

$$\sigma_y^2 = A\left[t - B\left(1 - e^{-t/B}\right)\right]$$

$$B = \frac{A}{2(\sigma_\theta \bar{u})^2}$$

$$A = 13 + 232(\sigma_\theta \bar{u})$$

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$$\frac{dQ}{dx\,dy} = -V_\Delta E_s$$

$$\frac{dQ}{dx} = \int_{-\infty}^{+\infty} V_\Delta \left[\frac{Qe^{-\frac{h^2}{2\sigma_z^2}} e^{-\frac{y^2}{2\sigma_y^2}}}{\pi \sigma_y \sigma_z 2\pi_h} \right] dy$$

$$\frac{dQ}{Q} = \sqrt{\frac{2}{\pi}} \left(\frac{V_d}{\pi_0}\right)\left(\frac{\pi_0}{\pi_h}\right) \frac{e^{-\frac{h^2}{2\sigma_z^2}}}{\sigma_z} dx$$

$$\frac{Q}{Q_0} = \exp\left[-\sqrt{\frac{2}{\pi}} \left(\frac{V_d}{\pi_0}\right)\left(\frac{\pi_0}{\pi_h}\right) \int_0^x \frac{e^{-\frac{h^2}{2\sigma_z^2}}}{\sigma_z} \right]$$

Dose

I Cloud Passage

A. External

1. $D_{TB} = \int_0^z \dot{c}_A \, dt$

$$\dot{d}_A = 0.7 \hat{E}_\gamma \, c_a$$

$$c_a = \left(\frac{Q}{\pi}\right)\left(\frac{E}{Q}\right)$$

$$D_{TB} = 0.7 \int_0^T F(T) \hat{E}_\gamma \left(\frac{Q}{\pi}\right)\left(\frac{E}{Q}\right) dt$$

$$D = f_1 f_2 \frac{\mu_0}{\lambda(\lambda_2 - \lambda)} \left\{ \lambda_2 (1 - e^{-\lambda t}) - \lambda (1 - e^{-\lambda_2 t}) \right\}$$

RADIOLOGICAL ENGINEERING

I. BASIC DESIGN FOR PERSONNEL PROTECTION

- A. Minimizing Personnel Exposure
  - 1. External
  - 2. Internal
- B. Contamination Control and Confinement

II. WASTE DISPOSAL

- A. Solid
- B. Liquid
- C. Gaseous

III. INSTRUMENTATION

- A. Personnel (Installed area monitoring systems)
- B. Process Monitoring
- C. Emergency

IV. SHIELDING

- A. Gamma Radiation
- B. Neutrons
- C. Development of Some Applicable Shielding Equations.
- C. Examples of Typical Problems

Radiological Engineering - Les Faust

Routinely Occupied	> 2 hr./day	≤ 0.2	mrem/hr
Non-routinely Occupied	< 2 hr./day	≤ 2.5	mrem/hr.

Location of areas
Limit movement of personnel and equipment
Office in point of minimum background
Use traffic patterns

Worry about test bed -