ANL-6769

Finkel

ANL-6769

Argonne National Laboratory

RADIOLOGICAL PHYSICS DIVISION

SUMMARY REPORT

July 1962 through June 1963

TABLE OF CONTENTS

TABLE OF CONTENTS

THE CONCENTRATION OF Ra^{226}, Ra^{228}, Pb^{210}, LEAD AND FLUORIDE IN HUMAN BONE FROM INDIVIDUALS WITH AN OSTEOGENIC SARCOMA

H. F. Lucas, Jr., Richard B. Holtzman and D. C. Dahlin*

Introduction

As part of a program to determine the toxicity to humans of internally deposited radioelements, we have studied the uptake and retention of Ra^{226}, Ra^{228}, Th^{228}, and Pb^{210} arising from the environment.[1-3] Since large amounts of Ra^{226} or other bone-seeking radioelements have been shown to produce a high incidence of osteogenic sarcoma,[4] it is conceivable that the normal natural environmental radiation may have a direct effect on the spontaneous incidence of this disease.

Natural levels of radium, however, are more than a factor of 10^4 lower than the levels known to be toxic and the range of the variations in dose is small. In addition, exposure is lifelong, and the dose is distributed more uniformly throughout the skeleton than that at the known toxic levels. In spite of these differences in deposition and dose, it has been presumed that the variation in natural radiation dose will result in a corresponding variation in the incidence of osteogenic sarcoma.

Naturally occurring radioisotopes which contribute significant radiation doses to bone include K^{40}, Ra^{226}, Ra^{228}, and Pb^{210}. The metabolism of K^{40} is such that there is little individual variation within a given age group.[5] We have, therefore, compared the Ra^{226}, Ra^{228}, and Pb^{210} content of the bone from normal individuals with that in proven cases of osteogenic sarcoma. In addition, we have determined the concentrations of two stable bone-seeking elements, lead and fluorine.

The concentrations of these nuclides depend on the environmental concentrations. Ra^{226} is acquired through both food and water, but since most of the world's population consumes water with no significant concentration of radium, food is the primary source. In these individuals the Ra^{226} concentration is low, and the values span a relatively small range. In some areas, however, the drinking water comes from wells which have a high Ra^{226} concentration, and individuals consuming this water may have body burdens 10 or more times higher than those whose only source of radium is food.[1] The Ra^{228} content of the body is similarly controlled, but because of the short half-life of the Ra^{228} (5.8 yr)[6,7] a variation with age of its concentration in the body exists. Thorium-228, a decay product

*Dept. Surgical Pathology, Mayo Clinic, Rochester, Minnesota.

of Ra^{228} is not appreciably absorbed from either food or water, and hence its presence in bone is due to the decay of its parent, Ra^{228}. Fluoride, like radium, enters the body primarily through food and drinking water, whereas Pb^{210} and lead are acquired from both food and air.

Experimental Method

For this study uninvolved bone was obtained from the area adjacent to the tumor. Although some samples had been stored in formalin, no contamination or leaching was found. When received, the samples were cleaned of soft tissue and bone marrow, dried at 110°C and stored in sealed polyethylene bags at a temperature of -27°C until analyzed.

Samples selected for analysis were given a preliminary treatment to remove blood residues by boiling three times in 50- to 100-ml portions of freshly distilled ethylene diamine, and three times in distilled water. A portion of each sample (approximately a one-third cross section) was then dried at 100°C, weighed, placed in a small (50 ml) platinum crucible and ashed at 600°C overnight in an electric muffle furnace lined with Crystalon* to reduce the possibility of contamination by the fire brick. The weighed ash was then transferred to a 50-ml centrifuge cone, dissolved with 1.85 ml concentrated nitric acid per gram ash, and diluted with distilled water to give 0.20 g ash/ml. No insoluble residue was observed.

The thorium was extracted into dibutyl phosphate, and the Th^{228} was determined using the procedure of Stehney et al.[8,9] Ra^{228} was determined from the grow-in of Th^{228} over a one- to two-year period. Since in most samples at the time of death the Th^{228}-to-Ra^{228} ratio was not significantly different from 1.0,[2] corrections (5% or less) were made for growth and decay between death and assay. Ra^{226} was determined by the emanation method previously described.[1] All computations necessary for the analysis of Ra^{226} and Ra^{228} were made on an IBM-704 computer. The estimate of the 90% confidence interval included the effect of the decay scheme on the counting statistics.[10]

Pb^{210} (RaD) was determined by wet ashing a dry, but otherwise untreated, portion of bone in concentrated nitric and perchloric acids. After repeated fuming with hydrochloric acid, the solution was converted to 0.5N HCl, from which the Pb^{210} daughter, Po^{210}, was plated onto a clean silver disk which was then counted for alpha particles. A repeat assay after 4 to 20 months was used to determine the Pb^{210} content at the time of death.

Stable lead was determined on a separate portion of bone which was ashed overnight at 600°C and dissolved in nitric acid. The lead was

*Cat. 204MC Lindberg Eng. Co. E. H. Sargent and Co., 4647 W. Foster Avenue, Chicago, Illinois.

extracted at pH 0.5 with diethyldithiocarbamide, back extracted with 6 N HCl, evaporated to dryness, and then determined spectrophotometrically with dithizone.[11]

Fluoride was determined in separate portions of bone ash by the diffusion method of Singer and Armstrong.[12] Comparison of these measurements with those of normal bone analyzed here and by others is discussed elsewhere.[13]

Results and Discussion

The samples chosen to represent bone from subjects with osteogenic sarcomas were specimens of bone removed in the treatment of this disease at the Mayo Clinic over a period of about a year. These subjects, with one exception, had been exposed only to natural environmental radium. The one exception had received the equivalent of an I.V. injection of about 400 μg radium and is discussed elsewhere.[14]

An osteogenic sarcoma is defined as a malignant tumor, the malignant cells of which produce osteoid tissue even if in only small foci. These sarcomas may be classified as osteoblastic, chondroblastic or fibroblastic depending on whether there is a predominance of osteoid, chondroid or fibromatoid differentiation. Osteogenic sarcomas may be graded from 1 to 4, the value corresponding to the degree of cellular dedifferentiation. As shown in Table 11, the distribution of the grades of malignancy in this series of 32 cases is similar to that in a larger series of 430 cases.[15] There is a corresponding similarity in the classification by histologic types as shown in Table 12. The sex ratio of 19 males and 13 females, and the anatomical distribution of skeletal involvement shown in Table 13, are also typical for any group of osteogenic sarcoma cases. The group of subjects selected for this study, therefore, appears to be a representative sample.

Table 11

Grade of malignancy

Grade	This series		430 Cases in overall series, Percent
	Number	Percent	
1	0	0	1.6
2	7	22	17.2
3	14	44	54.4
4	11	34	26.7

Table 12

Histologic types of osteogenic sarcoma

Type	This series		430 Cases in overall series, Percent
	Number	Percent	
Osteoblastic	20	63	50
Chondroblastic	4	12	27
Fibroblastic	8	25	23

Table 13

Skeletal localization of tumors

Location	Number of cases	Location	Number of cases
Fibula	1	Femur	21
Rib	1	Tibia	4
Humerus	5		

The measurements of the Ra^{226}, Ra^{228}, Pb^{210}, stable Pb and F in bone from these individuals having verified osteogenic sarcomas are summarized in Table 14. The mean Ra^{226} and Ra^{228} concentrations of

Table 14

Concentrations of Ra^{226}, Ra^{228}, Pb^{210}, Pb and F in bone ash of individuals with an osteogenic sarcoma

Sample No.	Age	Sex*	Bone	Ra^{226}, pC/g ash	Ra^{228}, pC/g ash	Pb^{210}, pC/g ash	Pb, µg/g ash	F, µg/g ash
524	20	M	Femur	0.008 ± 0.002	0.0030 ± 0.0014			199
407	17	M	Femur	0.011 ± 0.002	0.0036 ± 0.0021	0.109 ± 0.009		191
342	12	F	Femur	0.011 ± 0.003	0.005 ± 0.003	0.076 ± 0.006	9.5	244
411	15	F	Fibula	0.012 ± 0.002	0.0058 ± 0.0042		16.4	247
280	9	M	Femur	0.012 ± 0.003	0.007 ± 0.003	0.075 ± 0.003	4.2	140
370	23	M	Femur	0.013 ± 0.0014	0.004 ± 0.001	0.061 ± 0.007	17.7	190
384	11	F	Femur	0.013 ± 0.002	0.0057 ± 0.0014	0.077 ± 0.007	9.9	192
282	50	F	Femur	0.013 ± 0.001	0.002 ± 0.001	0.054 ± 0.006	22.0	620
378	15	F	Femur	0.016 ± 0.002	0.006 ± 0.002	0.043 ± 0.003		123
522	14	M	Tibia	0.016 ± 0.003	0.0048 ± 0.0017			83
376	23	M	Femur	0.017 ± 0.002	0.0032 ± 0.0012	0.054 ± 0.006	24.0	110
554	13	M	Humerus	0.018 ± 0.014	0.0056 ± 0.0032			
412	44	M	Femur	0.020 ± 0.001	0.0037 ± 0.0023	0.097 ± 0.008	13.8	390
283	12	M	Femur	0.020 ± 0.003	0.006 ± 0.002	0.042 ± 0.005	7.0	83
539	17	M	Humerus	0.022 ± 0.003	0.0054 ± 0.0019		10.8	930
368	67	M	Femur	0.023 ± 0.003	0.005 ± 0.002	0.105 ± 0.006	15	456
483	27	M	Femur	0.024 ± 0.003	0.0071 ± 0.0021		6.5	1110
369	16	M	Humerus	0.027 ± 0.002	0.007 ± 0.001	0.054 ± 0.008	7.6	465
408	32	M	Femur	0.031 ± 0.003	0.0072 ± 0.0028	0.099 ± 0.008		1190
379	14	F	Femur	0.033 ± 0.002	0.0098 ± 0.0018	0.064 ± 0.008		81
386	12	F	Humerus	0.033 ± 0.006	0.0090 ± 0.0088			210
523	47	F	Tibia	0.033 ± 0.006	0.0083 ± 0.0019			533
375	30	F	Femur	0.035 ± 0.006	0.008 ± 0.001	0.092 ± 0.011	20.6	251
387	13	M	Femur	0.037 ± 0.003	0.0133 ± 0.0058			134
377	15	F	Femur	0.038 ± 0.002	0.0085 ± 0.0017	0.088 ± 0.011	24.7	135
409	47	M	Femur	0.038 ± 0.003	0.0032 ± 0.0019	0.072 ± 0.007	24.5	944
373	46	F	Humerus	0.042 ± 0.002	0.004 ± 0.002	0.110 ± 0.009	25.9	998
367	48	M	Rib	0.044 ± 0.004	0.016 ± 0.003		25.8	608
374	62	F	Tibia	0.048 ± 0.003	0.018 ± 0.002		26.2	1080
278	59	M	Tibia	0.060 ± 0.002	0.010 ± 0.001	0.182 ± 0.010		1150
383	13	M	Femur	0.058 ± 0.003	0.0130 ± 0.0043	0.066 ± 0.007		386
372	7	F	Femur	0.075 ± 0.003	0.019 ± 0.002	0.063 ± 0.008	22.6	223
Mean ± Std. Dev.				0.028 ± 0.016	0.007 ± 0.004	0.080[21] ± 0.031	16.7[20] ± 7.6	411 ± 371

*M = male, F = female

0.028 ± 0.016 and 0.007 ± 0.004 pC/g ash, respectively, are significantly higher ($P < 0.001$) than the 0.0124 ± 0.005 pC Ra^{226}/g ash and 0.003 ± 0.002 pC Ra^{228}/g ash found in individuals consuming water of low radium content.[1,2] In contrast, the Pb^{210}, stable lead, and fluoride concentrations of 0.080 pC/g ash, 17 μg/g ash, and 411 μg/g ash, respectively, are not significantly different from those in individuals not having osteogenic sarcomas.[3,1,13]

The somewhat high value of the mean Ra^{226} concentration found in this survey may be shown to correlate very well with the probable Ra^{226} intake of these subjects and, thus, is not due to metabolic differences. In nineteen of the osteogenic sarcoma cases, the residential history was sufficiently stable and water samples were available so that comparison could be made with the uptake previously observed for other individuals. The expected concentration of Ra^{226} in bone ash, R, was computed from the following equation:[1]

$$R = 0.0124 + 0.002\ C_w \qquad (1)$$

where R is in units of pC Ra^{226}/g ash and C_w is the concentration of Ra^{226} in drinking water in units of pC Ra^{226}/liter. When extrapolated to the 2600 g of ash in a Standard Man, this corresponds to a body content equal to that from food plus that contained in 52 liters of drinking water. The observed and calculated concentrations are shown in Table 15. The means of these concentrations, 0.025 pC/g ash and 0.032 pC/g ash respectively, are not statistically different ($P < 0.01$). Thus, the overall metabolism of radium in patients with an osteogenic sarcoma does not appear to be significantly different from that in other individuals.

Table 15

Comparison of the observed and calculated concentrations of Ra^{226} from osteogenic sarcoma cases

Observed	Calculated
0.052	0.075
0.046	0.060
0.042	0.065
0.033	0.020
0.033	0.025
0.030	0.015
0.030	0.043
0.027	0.017
0.023	0.069
0.022	0.015
0.021	0.015
0.020	0.050
0.018	0.015
0.016	0.022
0.013	0.023
0.013	0.017
0.012	0.025
0.012	0.018
0.011	0.015
Mean 0.025 ± 0.016	0.032 ± 0.021

Evaluation of the total radiation dose requires information about type of housing and medical X-ray exposure history which is not now available. If, however, we compare only the internal radiation dose in these patients with that of the average person, an indication of the significance of internal emitters may be inferred. The absorbed dose ratios for equal concentrations (pC/g ash) of Ra^{226}, Ra^{228}, and Pb^{210} are 3:6:1; i.e. 3 pC/g Ra^{226} gives the same dose rate in rads per unit time as 6 pC/g Pb^{210} or 1 pC/g Ra^{228}. As shown in Table 16, the Ra^{226} and Ra^{228} concentrations are higher in bone of osteogenic sarcoma patients than in bone from the average person. However, the lower Pb^{210} concentrations compensate to reduce the difference in dose to insignificance particularly in view of the larger K^{40} contribution. The increase in the radium dose rate is only 2 mrad/yr which is only about 10% of the total dose from the internal emitters. If one also includes the average radiation dose rate to the skeleton from cosmic and terrestrial sources of about 80 mrad/yr,[16] then the 2 mrad/yr difference in radium dose rate amounts to only about 2% of the total. The relative biological effectiveness (RBE) of the various radiations, however, has not been considered.

Table 16

Comparison of absorbed dose to the skeleton from internal emitters in average individuals and in those with an osteogenic sarcoma

Emitter	Average individual		Osteogenic sarcoma patient	
	pC/g ash	mrad/yr	pC/g ash	mrad/yr
Ra^{226}	0.012	1	0.027	2
Ra^{228}	0.003	0.4	0.007	1
Pb^{210}*	0.105	4	0.080	3
K^{40}	-	10	-	10
Total		15.4		16

*Values in cortical bone

Unfortunately, good values for the relative biological effectiveness of the radiations involved in the continuous, low-level human exposure are not available, and the dose equivalent,* (RBE dose), cannot be estimated with any degree of certainty. Since the RBE for alpha-particle irradiation appears to be greater than one, the effect of the irradiation from Ra^{226},

*As defined in Reference 17.

Ra^{228} and Pb^{210} may be greater than that from the other internal emitters. However, the same RBE factor must be used for the normal individual as for the one having an osteogenic sarcoma so that the difference in dose is still relatively small.

In addition, no great significance can be attached to the slightly higher dose rates calculated for the osteogenic sarcoma cases because the hospital from which the osteogenic sarcoma samples were obtained is located within the geographical area having high concentrations of radium in municipal waters. Consequently, one expects a higher skeletal concentration of Ra^{226} and Ra^{228} in these individuals than in those from other areas.

In conclusion, this study has demonstrated that for an individual with an osteogenic sarcoma, the internal dose rate, radium metabolism, and possibly the metabolism of Pb^{210}, stable lead and fluoride, do not differ significantly from those of the average human being. Thus, in future studies, the metabolism of these substances by individuals with osteogenic sarcomas may be assumed to be identical to those of the unaffected population, so that measurements on the former group are unnecessary.

While it is conceivable that the variation in environmental radiation may have a direct effect on the spontaneous incidence of osteogenic sarcoma in man, this study is not suitable for this purpose. Estimation of the osteogenic sarcoma incidence requires knowledge of the population at risk for each of the dose levels. Although these data are available for a limited geographical area, they are not available for the region in which these individuals lived. This estimate must await completion of an epidemiological study such as is in progress in the Midwest.

We are very much indebted to Marvin M. D. Williams, J. E. Rose, A. J. Finkel, and L. D. Marinelli for their interest and assistance in initiating this study. Very great thanks are due J. Kann, F. H. Ilcewicz, F. Markun and T. Kinsella for their very considerable contributions.

References

1. H. F. Lucas. Correlation of the natural radioactivity of the human body to that of its environment: Uptake and retention of Ra^{226} from food and water. Radiological Physics Division Semiannual Report, July through December 1960, Argonne National Laboratory. ANL-6297, pp. 55-66.

2. H. F. Lucas, Jr., D. E. Wallace, A. F. Stehney and F. H. Ilcewicz. Correlation of the Ra^{228} and Ra^{226} content of man with that of the food and water of his environment. Second Intern. Cong. of Radiation Research, Harrogate, England, August 5-11, 1962. Abstracts of Papers, p. 102.

3. R. B. Holtzman. Measurement of the natural content of RaD(Pb^{210}) and RaF(Po^{210}) in human bones - estimates of whole-body burdens. Health Phys. 9, 385 (1963).

4. A. J. Finkel, C. E. Miller, and R. J. Hasterlik. Late effects of radium deposition in dial painters. Radiation Res. 11, 442 (1959).

5. G. R. Meneely, R. M. Heyssel, C. O. T. Ball, R. L. Weiland, A. R. Lorimer, C. Constantinides, and E. U. Mencely. Analysis of factors affecting body composition determined from potassium content in 915 normal subjects. Ann. N. Y. Acad. Sci. 110, 271-281 (1963).

6. C. W. Mays, D. R. Atherton, F. W. Bruenger, B. J. Stover, W. M. Hammer, and W. W. Parmley. Redetermination of the half-period of Ra^{228} (mesothorium). Research in Radiobiology, Report COO-222 (1960), pp. 27-48.

7. C. W. Mays, D. R. Atherton, R. D. Lloyd, H. F. Lucas, Jr., B. J. Stoner, and F. W. Bruenger. The half-period of Ra^{228} (mesothorium). Research in Radiobiology, Report COO-225 (1962), pp. 92-105.

8. A. F. Stehney and D. E. Wallace. Dibutyl phosphate as an extractant of radiothorium from bone. Radiation Res. 5, 598 (1956).

9. D. E. Wallace, A. F. Stehney, and F. H. Ilcewicz. Calibration of dibutyl phosphate procedure for isolation of Th^{228} from bone. Radiological Physics Division Semiannual Report, January through June 1957, Argonne National Laboratory. ANL-5755, p. 33.

10. H. F. Lucas, Jr. and D. A. Woodward. Effect of long decay chains on the counting statistics in the analysis of Ra^{224} and Ra^{222}. Radiological Physics Division Semiannual Report, January through June 1962, Argonne National Laboratory. ANL-6646, pp. 78-91.

11. Douglas P. Krause. Stable lead in human bone. Radiological Physics Division Semiannual Report, January through June 1961, Argonne National Laboratory. ANL-6398.

12. L. Singer and W. D. Armstrong. Determination of fluoride (procedure based on the diffusion of HF). Anal. Chem. 26, 904 (1954).

13. F. H. Ilcewicz, H. F. Lucas, Jr., and R. B. Holtzman. Normal fluoride concentration in human bone, this report p. 79.

14. H. F. Lucas, Jr., R. E. Rowland, C. E. Miller, R. B. Holtzman, R. J. Hasterlik, and A. J. Finkel. An unusual case of radium toxicity. Am. J. Roentgenol. 90(5) 1040-1051 (November 1963).

15. M. B. Coventry and D. C. Dahlin. Osteogenic sarcoma. A critical analysis of 430 cases. J. Bone and Joint Surg. 39-A, 741-757 (1957).

16. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, Supplement No. 17 (A/3838), New York, 1958.

17. Report of the RBE Committee to the International Commissions on Radiological Protection and on Radiological Units and Measurements. Health Phys. 9, 357-384 (1963).

THE LEVEL OF RADIUM IN HUMAN BLOOD FORTY YEARS AFTER INGESTION

H. F. Lucas, Jr., J. H. Marshall, and L. A. Barrer*

Considerable information about radium metabolism has been obtained from measurements of radium retained at long times after exposure and from autoradiographic and microradiographic studies of the deposits in the bone.[1,2] From theoretical considerations of the possible physical-chemical and biological process involved[3-5] the importance of blood radium concentrations was apparent. While measurements at relatively short times after injection of Ra^{226} have been reported by Aub et al.[6] and by Mays et al.,[7] no measurements are available of the Ra^{226} in human blood at long times after exposure. It has been suggested by Rowland[8] that the value by Aub et al.[6] may be high owing to the medication given which had increased the daily rate of elimination by a factor of 3 to 6.

Samples of whole blood, cell-free serum, and cells containing some serum were obtained from four former New Jersey dial painters. The blood samples were obtained with a blood-letting needle under gravity flow to minimize cell fracture. Serum was obtained by placing about 30 ml whole blood in a clean 50-ml centrifuge tube, allowed to stand at room temperature for 20-30 min and then centrifuged for 10 min. The serum and cells were decanted into small bottles, frozen with solid carbon dioxide (-80°C), and sent to the Argonne National Laboratory for assay. No hemolysis was visible, and the serum is believed to be cell free.

Urine and fecal samples were obtained for three-day periods at about monthly intervals. Complete collection of urine was obtained for a total of 12 days, except for Case No. 5215 which was for 3 days. While complete collection of feces (12 days) was obtained for Case Nos. 5284 and 5025, only 7 and 3 day samples were obtained for Cases 5281 and 5215, respectively. For these last two cases, daily samples were not obtained, and further samples are required accurately to establish the fecal excretion rate.

The whole-body Ra^{226} content of these patients was determined by C. E. Miller using the tilting chair and multicrystal counting arrangements previously described.[9] The Ra^{228} burden was low in all cases and could be disregarded. Breath radon samples were taken using the standard helmet and alpha scintillation radon counter system.[10,11] For each subject, five samples of breath, each of ten minutes' duration, were taken. The helmet was worn for 90 to 115 minutes with each subject lying on a bed. Calculation of the emanating Ra^{226} was made from the time duration of breath collection.[10]

*Radium Research Project, New Jersey State Dept. of Health, West Orange, N. J.

The results of the gamma-ray and breath-radon measurements are summarized in Table 17. Subjects 5215 and 5281 were very apprehensive and uncomfortable in the helmet, as evidenced by a high respiratory rate of 20 to 24 exhalations per minute. The 20% variation between successive 10-min samples in subject 5215 is typical for apprehensive individuals. The much larger variation for subject 5281 has not been previously observed. In contrast, the nearly constant radon exhalation by subject 5284 is typical of patients who are completely relaxed or asleep. The Rn/Ra ratio ranged from 0.63 to 0.71; the average of 0.68 is not significantly different from the 0.69 found in other radium cases.(1)

Table 17

Summary of breath radon and gamma ray measurements of four New Jersey cases

Subject	Emanating radium, μg						Gamma-ray Ra^{226}, μg	Rn/Ra	Total Ra^{226}, μg
	First	Second	Third	Fourth	Fifth	Mean			
5215	0.99*	1.00	0.98	0.86	0.78	0.92	0.43	0.68	1.35
5281	0.55	0.52	0.40	0.39	0.32	0.44	0.18	0.71	0.62
5284	0.167	0.150	0.147	0.149	0.156	0.154	0.09	0.63	0.24
5025	0.123	0.069	0.067	0.078	0.087	0.084	0.040	0.68	0.12

*May be low by 5% or less due to analytical error.

Measurements of the Ra^{226} in blood, feces, urine and body of the four subjects are summarized in Table 18. As has been found previously,(1) the radium excreted in the urine is a small fraction of the total ranging from 0.7 to 2.6% with an average of 1.7%. The average daily Ra^{226} excretion divided by the body burden gives a coefficient of elimination ranging from 0.5 to 1.2 x 10^{-4} day^{-1} with an average of 0.80 x 10^{-4} day^{-1}. The

Table 18

Summary of Ra^{226} measurements in blood, feces, urine, and body of four New Jersey cases

Case number	5281	5215	5284	5025
Age	64	76	63	69
Years carried	39	45	45	45
Body Ra^{226}, μc	0.62	1.35	0.24	0.12
Feces, pc/day	30.9(7)	118(3)	28.2(12)	7.5(12)
Urine, pc/day	0.40 ± 0.03	0.86 ± 0.05	0.70 ± 0.03	0.18 ± 0.03
Urine/feces, %	1.3	0.7	2.5	2.4
Serum, pc/kg	0.34 ± 0.15	0.50 ± 0.24	0.54 ± 0.15	-
Cells, pc/kg	0.03 ± 0.10	0.21 ± 0.18	0.34 ± 0.13	-
Whole blood, pc/kg	0.18 ± 0.04	0.50 ± 0.05	0.25 ± 0.05	0.12 ± 0.04
Blood clearance, liters/day				
Urine	2.2 ± 0.6	1.7 ± 0.1	2.8 ± 0.3	1.4 ± 0.3
Feces	170	240	115	60

range and average values are not significantly different from the average of ten cases for which Norris et al.[1] found 0.80×10^{-4} day^{-1} about 20 years after injection. The similarity in the coefficient of elimination in these four cases, 40 years after ingestion, with that at 20 years suggests that the power law may break down at these long times. In any case, these findings are important enough to require confirmation.

Measurements of the Ra^{226} in the serum, cells and whole blood for these four cases is also summarized in Table 18. Since the calcium content of these samples has not yet been determined, a detailed and complete interpretation of the significance of these measurements will not be made at this time. However, if the accepted average calcium content in the serum and the whole blood in humans is assumed, then the calculated radium/calcium ratio in these tissues is less than 1% of the average for the skeleton. From the radium content of the whole blood and the excreta, clearance of radium by the kidney and the G. I. tract are found to range from 1.4 to 2.8 and 60 to 240 liter/day, respectively. These values are to be compared with a plasma clearance of 0.5 liter/day for the kidney and 69 liter/day for the G. I. tract which was found by Mays et al.[7] a few days after a single I. V. injection.

Very great thanks are due F. H. Ilcewicz, F. Markun and T. Kinsella for assistance in preparing and analyzing the samples.

References

1. W. P. Norris, T. W. Speckman, and P. F. Gustafson. Studies of the metabolism of radium in man. Am. J. Roentgenol. 73, 785-802 (1955).

2. R. E. Rowland, J. H. Marshall, and J. Jowsey. Radium in human bones: The microradiographic appearance. Radiation Res. 10, 323-334 (1959).

3. R. H. Holtzman. The kinetics of alkaline earth metabolism in animals. II extension of concepts. this report p. 112.

4. D. N. Edgington. Crystal growth - a new physical approach to the deposition of radioactive isotopes in bone, this report p. 127

5. J. H. Marshall. Theory of alkaline earth metabolism. Radiological Physics Division Semiannual Report, January through June 1962, Argonne National Laboratory. ANL-6646, pp. 5-29.

6. J. C. Aub, R. D. Evans, D. M. Gallagher, and D. M. Tibbetts. Effects of treatment on radium and calcium metabolism in the human body. Ann. Intern. Med. 11 (8), 1443-1463 (1938).

7. C. W. Mays, R. D. Lloyd, W. R. Christensen, D. R. Atherton, and G. S. Pitchford. Radium metabolism in man. Radiation Res. 19, 210 (1963).

8. R. E. Rowland. Retention and plasma clearance of the alkaline earth elements. Radiological Physics Division Semiannual Report, July through December 1959, Argonne National Laboratory. ANL-6104, pp. 34-40.

9. C. E. Miller. An experimental evaluation of multiple-crystal arrays and single crystal techniques. Whole Body Counting. Intern. Atomic Energy Agency, Vienna, 1962. pp. 81-120.

10. H. F. Lucas and A. F. Stehney. Radon contamination in the measurement of low levels of expired radon. Radiological Physics Division Semiannual Report, January through June 1956, Argonne National Laboratory. ANL-5596, pp. 6-11.

11. H. F. Lucas, Jr. Improved low-level alpha scintillation counter for radon. Rev. Sci. Instr. 28, 680-683 (1957).