183/ 2-25-77

ANL-76-88

Part II

Dr 740

ANL-76-88

Part II

RADIOLOGICAL AND ENVIRONMENTAL RESEARCH DIVISION ANNUAL REPORT

Center for Human Radiobiology

July 1975—June 1976

MASTER

U of C-AUA-USERDA

ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

Prepared for the U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION under Contract W-31-109-Eng-38

DISCLAIMER

Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161
Price: Printed Copy $7.50; Microfiche $3.00

Distribution Category:
Biology and Medicine
(UC-48)

ANL-76-88
Part II

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

RADIOLOGICAL AND ENVIRONMENTAL RESEARCH DIVISION ANNUAL REPORT

Center for Human Radiobiology

July 1975 through June 1976

R. E. Rowland, Division Director
A. F. Stehney, Section Head

Preceding Report: ANL-75-60, Part II, July 1974–June 1975

FOREWORD

The papers in this report deal with several different aspects of the Center's studies of the effects of internally deposited radionuclides in humans: experimental and theoretical research on the induction of tumors by alpha-particle irradiation (papers 1–4); medical effects (papers 5–8); metabolism and dosimetry (papers 9–17); methods for the determination of radioactivity (papers 18–25); and processing of data (papers 26–27).

The reader's attention is directed to paper 1, which reports that the mean lethal dose for mammalian cells corresponded to about 27 alpha particles per cell nucleus when cultured cells were irradiated with 5.6 MeV alpha particles. This finding casts doubt on the common supposition that a single alpha particle through the nucleus is sufficient to kill a cell in situ. Also of special interest is the report on a case of internal contamination with ^{241}Am plated on silver for use in smoke detectors (paper 16). Two disks, accidentally swallowed in the same incident, were found to have lost less than 1% of the americium in passing through the gastrointestinal tract.

Exposure data for persons whose body burdens of radium have been measured are given in Appendix A at the back of this report. As was the case in our previous Annual Report (ANL-75-60, Part II), tumor cases considered to have radium-induced malignancies are listed in Appendix B for persons whose body burdens of radium have been measured: bone sarcomas in Table 1 and carcinomas of the paranasal sinuses and mastoid air cells in Table 2. To these we have now added lists of "probable or confirmed" malignancies of the same types in persons known to have been exposed to radium, but whose body burdens have not been determined (Appendix B, Tables 3 and 4). These are mostly persons who died before population studies of radium-exposed persons were initiated in the 1950's. The cases of suspected radium-induced malignancy were identified by careful review of case histories for any indication of bone sarcoma or carcinoma of the sinuses or mastoids. This review included all persons for whom any medical data were available at the end of 1975.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

TABLE OF CONTENTS

Center for Human Radiobiology

Foreword

1. Cell Survival Following Alpha Particle Irradiation: Critical Sites and Implications for Carcinogenesis — 1
   E. L. LLOYD, M. A. GEMMELL, C. B. HENNING, D. S. GEMMELL, AND B. J. ZABRANSKY

2. Electron Microscope Studies of Viruses in Tumors Induced by ^{239}Pu in Mice — 12
   E. L. LLOYD AND J. F. LOUTIT

3. Hazard Plotting and Estimates for the Tumor Rate and the Tumor Growth Time for Radiogenic Osteosarcomas in Man — 17
   PETER G. GROER AND JOHN H. MARSHALL

4. Variance of the Number of Tumors in a Model for the Induction of Osteosarcoma by Alpha Radiation — 22
   PETER G. GROER AND JOHN H. MARSHALL

5. Long-Term Effects of Radium Exposure in Female Dial Workers: Hematocrit and Blood Pressure — 26
   A. P. POLEDNAK

6. Adult Height and Weight of Female Radium Dial Painters, with Analysis of Radiation Effect on Growth — 27
   A. P. POLEDNAK

7. Plugged Haversian Canals and Skeletal Dose in Radium Cases — 28
   DAVID J. SIMMONS, A. T. KEANE, RICHARD B. HOLTZMAN, AND J. H. MARSHALL

8. Chromosome Aberrations in the Peripheral Lymphocytes of Thorium Workers with Low Body Burdens of ^{212}Bi — 30
   S. F. HOEGERMAN

9. Gross Distribution of ^{226}Ra in Man from External Counting — 38
   J. RUNDO, M. A. ESSLING, AND D. R. HUFF

10. The Macrodistribution of ^{226}Ra in the Skeleton of a Radium Dial Painter — 40
    R. B. HOLTZMAN AND D. J. SIMMONS

11. Microscopic Distribution of ^{226}Ra in the Bones of Radium Cases: A Comparison between Diffuse and Average ^{226}Ra Concentrations — 41
R. A. SCHLENKER AND J. E. FARNHAM

12. Macrodistribution of Plutonium in Selected Bones from an Abnormal Skeleton — 42
R. P. LARSEN, R. E. TOOHEY, AND F. H. ILCEWICZ

13. Microscopic Distribution of ^{239}Pu Deposited in Bone from a Human Injection Case — 45
R. A. SCHLENKER, BILLIE G. OLTMAN, AND HELEN T. CUMMINS

14. Comparison of the Late Excretion of ^{226}Ra and ^{239}Pu by Man — 46
J. RUNDO AND R. B. HOLTZMAN

15. Variability in the Exhalation Rate of Radon — 47
J. RUNDO, F. MARKUN, J. Y. SHA, AND P. CAMERON

16. An Unusual Case of Internal Contamination with ^{241}Am — 54
J. RUNDO, M. ESSLING, D. R. HUFF, AND W. D. FAIRMAN

17. Marrow, Ovary, and Breast Doses Delivered by CHR Diagnostic X-Ray Procedures — 62
R. A. SCHLENKER AND B. G. OLTMAN

18. The Macrodistribution of ^{226}Ra in the Human Skeleton as Determined In Vitro by Gamma-Ray Spectrometry — 70
M. A. ESSLING AND D. R. HUFF

19. Methods for the Assay of Plutonium In Vivo: What Are The Alternatives? — 80
J. RUNDO, M. G. STRAUSS, I. S. SHERMAN, AND R. BRENNER

20. The Use of ^{103}Pd as a Calibration Source for the Determination of ^{239}Pu In Vivo — 82
R. E. TOOHEY

21. Relative Abundances of Uranium $L_{\alpha,\beta,\gamma}$ Conversion X Rays Following α-Decay of Plutonium — 86
R. E. TOOHEY

22. Progress Report on the Development of the Fission Track Method for the Determination of Plutonium in Biological Materials — 90
R. P. LARSEN AND R. D. OLDHAM

23. X-Ray Spectrometric Determination of Thorium in Bone and Other Biological Materials — 94
R. P. LARSEN AND P. W. URNEZIS

24. Counting Chamber for Alpha-Spectrometric Measurements — 96
R. P. LARSEN AND R. F. SELMAN

25. A Microprocessor-Assisted Calibration for a Remote Working Level Monitor — 99
W. P. McDOWELL, D. J. KEEFE, P. G. GROER, AND R. T. WITEK

26. Computer Storage of Data Obtained in the Measurement of Radium In Vitro — 100
M. A. ESSLING AND D. R. HUFF

27. Expansion of the CHR Bone Code System — 102
J. E. FARNHAM AND R. A. SCHLENKER

Appendix A — 109

Appendix B — 167

Publications — 172

CELL SURVIVAL FOLLOWING ALPHA PARTICLE IRRADIATION: CRITICAL SITES AND IMPLICATIONS FOR CARCINOGENESIS

E. L. Lloyd, M. A. Gemmell, C. B. Henning, D. S. Gemmell,* and B. J. Zabransky*

In experiments in which mammalian cells were irradiated with 5.6 MeV alpha particles from a Tandem Van de Graaff machine we have confirmed the finding of others that the mean lethal dose (D_0) is about 100 rad, but by measurements of the area of the cell nuclei as irradiated we found that this mean lethal dose corresponds not to 1, as expected,[1–6] but to about 27 alpha particles per cell nucleus. (The exact number appears to change slightly with cell passage number.) This allows for the possibility that the direct action of alpha particles on the nucleus may be the important event in carcinogenesis, a theory which was previously difficult to accept if a single particle hitting the nucleus anywhere was considered to be lethal.

Evidence is presented to implicate the nucleolus as a possible critical site for the inhibition of reproductive integrity of the cell.

Introduction

In an experiment designed to simulate, in vitro, the effects of radiation from ^{226}Ra on cells adjacent to bone surfaces in vivo, cells were irradiated with a parallel beam of alpha particles from a Tandem Van de Graaff with an energy of 5.6 MeV, about the average energy of alpha particles from radium and its daughter products.

The cells chosen for irradiation were a well characterized cell line[7] of normal mouse embryo fibroblasts, (C3H 10 T 1/2). Since previous workers had found that the mean lethal dose for cells corresponded to a cross section for cell killing approximately equivalent to the passage of a single alpha particle through the area of the cell nucleus in projection,[1–6] the nuclear areas of the cells used here were measured prior to the first irradiation experiment, and the alpha particle fluences were adjusted to cover a range of fluences about a factor of two on either side of this value of one alpha per nuclear area. To our great surprise in this preliminary experiment, no significant cell killing was detected. However, when the cell thickness was measured in order to

---

*ANL Physics Division

determine the energy deposited in the cell layer, the dose in rad turned out to be much lower than that reported by others for the mean lethal dose. Details of this experiment and those done subsequently with higher doses are reported here.

Methods and Materials

Cells and Culture

The cell line (10 T 1/2, clone 8) chosen for this experiment was kindly provided by Dr. Charles Heidelberger (McArdle Laboratory for Cancer Research, University of Wisconsin, Madison).

Cells were grown in Eagle's basal medium containing 10% fetal calf serum and 1% gentamycin in 75 cm^2 Falcon plastic flasks. The stock solutions were fed twice weekly and transferred when semiconfluent. Cells from these flasks were seeded in 1 ml of medium onto a 2-in-diameter circle in the center of a 100-mm-diameter plastic Petri dish for the irradiation experiments. The cells were placed in the incubator for 2 hr to allow them to become firmly attached before adding 20 ml of media. Twenty-four to 48 hr later the cells were removed from the incubator for irradiation. Immediately prior to irradiation, the media was removed from the cells by tilting the plate and sucking off the fluid for 20 sec with a Pasteur pipette attached to a vacuum pump. The irradiation times varied from 2 to 25 sec. Immediately after irradiation, the cells were replenished with medium and placed in the incubator. Within 6 hr following their radiation, the cells were trypsinized, diluted and plated at a concentration to give about 60 colonies/75-cm^2 dish to determine viability.[8] The colonies were counted 10 to 14 days after plating.

Electron Microscope Technique

Electron microscope studies were made both on cells which were trypsinized and embedded as a pellet and on cells embedded in situ to document the appearance of the cells as they were irradiated. The cells used for both studies were rinsed with 0.1 M caccodylate buffer at pH 7.3. The trypsinized cells were placed in 15-ml Falcon plastic centrifuge tubes, centrifuged, decanted, and rinsed again with buffer before fixation. The cells embedded in situ were also washed and rinsed before fixation. The fixative used in both cases was a 3% solution of glutaraldehyde in 0.1 M caccodylate buffer. The technique used for the in situ embedding was essentially the same as that described by Douglas et al.[9] Following fixation, the cells were washed three times with 0.2 M buffer and then postfixed for 1 hr with 1% osmium tetroxide in 0.1 M caccodylate buffer followed by another buffer rinse. Dehydration was carried out using 10-min rinses in each of a series of ethanols (30%, 50%, and 75%). Subsequently, the cells were placed for 15 min in each of a series of graded concentrations of hydroxypropyl methacrylate (HPM) in 100% ethanol (70%, 90%, and 100%). For the preliminary infiltration, a mixture of HPM and Epon-Araldite in a 1:1 ratio was used for 1 hr; the final infiltration was carried out overnight in 100% Epon-Araldite. The next morning the resin was discarded from the Petri dishes, 4 ml of fresh Epon-Araldite was added, and the dishes were placed in a 60 C oven for 24 hr. After the initial polymerization, the layer of Epon-Araldite with the embedded cells was peeled off the bottom of the dish, and small pieces were trimmed and reimbedded in Beem capsules, in both horizontal and vertical orientations. The final polymerizations were made in a 60 C oven for 48 hr, for the reimbedded cells, and for 72 hr for the trypsinized cells, which were transferred from the resin directly to the Beem capsules. The blocks were trimmed by hand and sectioned on a Huxley ultramicrotome using a diamond knife. The sections were mounted on copper grids and stained with uranyl acetate (2 hr) followed by a lead citrate counterstain (3 min). After drying the cells were viewed and photographed using a Siemens Elmiskop type 1A electron microscope.

Irradiation

Details of the experimental design for the irradiation are shown in Figure 1. The alpha particle energy was 5.6 MeV; fluences were measured using a Faraday cage and checked for uniformity and absolute numbers with Type A α track plates, which were placed in the same position as the cells for irradiation.

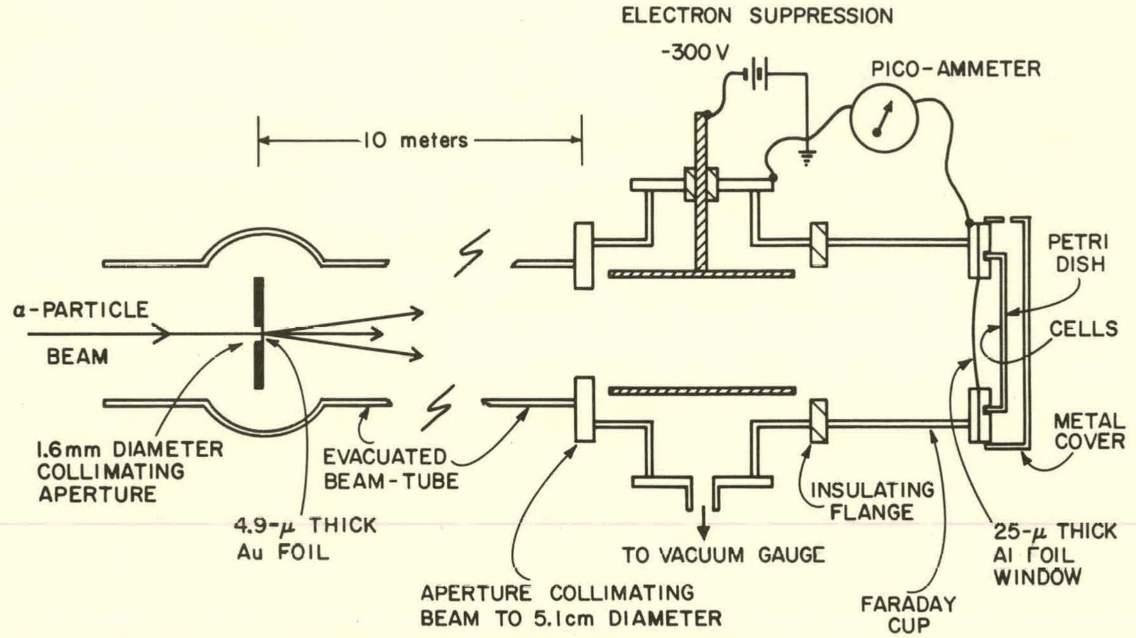

FIG. 1.--Schematic representation of the experimental arrangement used to irradiate the cells with α particles from a Tandem Van de Graaff machine. (ANL neg. 209-76-248)

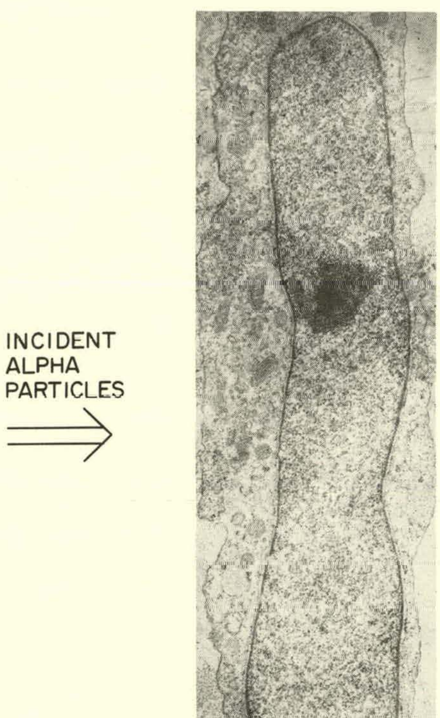

FIG. 2.--An electronmicrograph illustrating the flattened appearance of the mouse embryo fibroblasts as they were irradiated on the surface of a plastic Petri dish. (ANL Neg. 149-76-267)

Results

The dimensions and the orientation of the cells used in this experiment were determined by using both the light microscope and the electron microscope. Figure 2 illustrates the "pancake" appearance of the cells as seen at right angles to the beam; Figure 3 shows the rounded appearance of several cells as they normally appear in suspension. From the measurement of ten nuclei

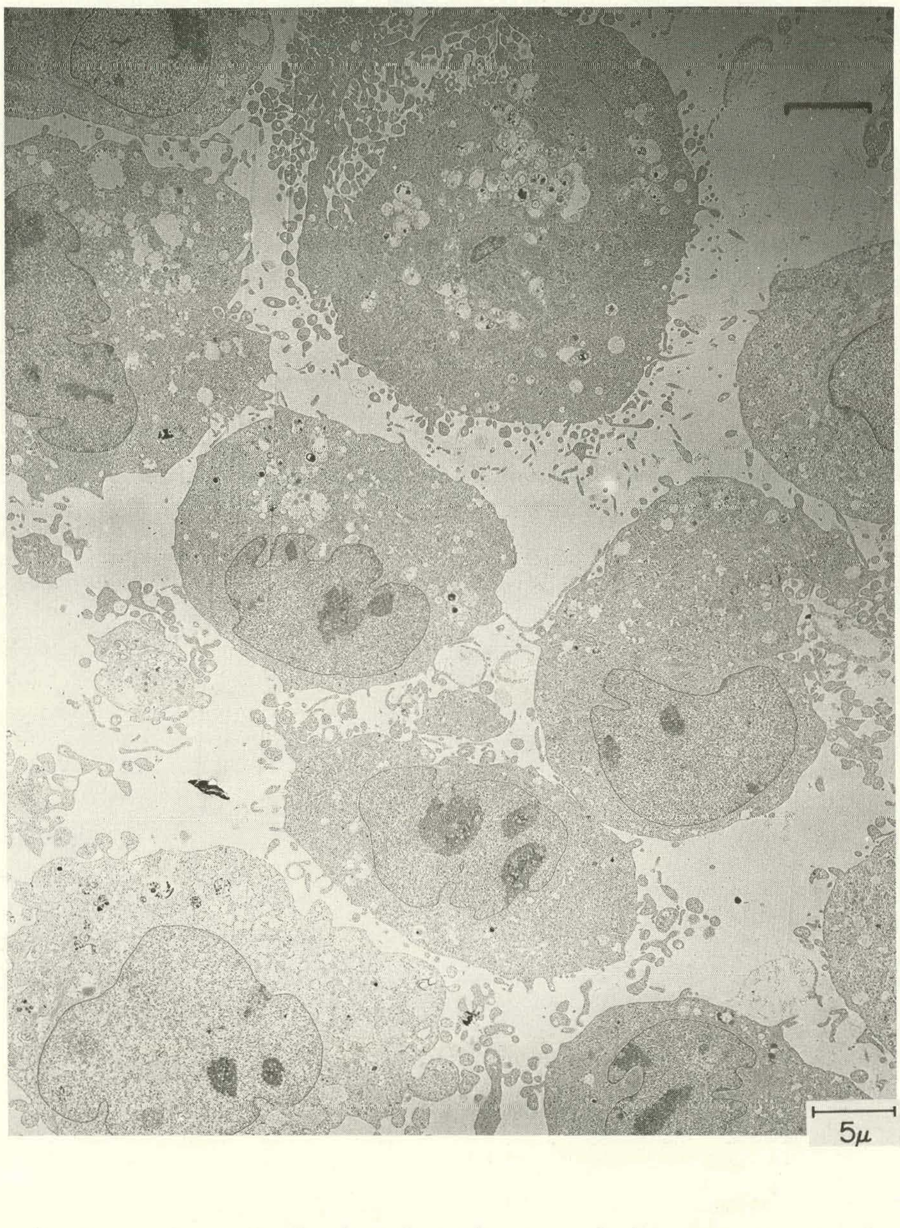

FIG. 3.--An electronmicrograph showing the rounded appearance of cells fixed in suspension. The cells were taken from the same culture as those seen in Figure 2.

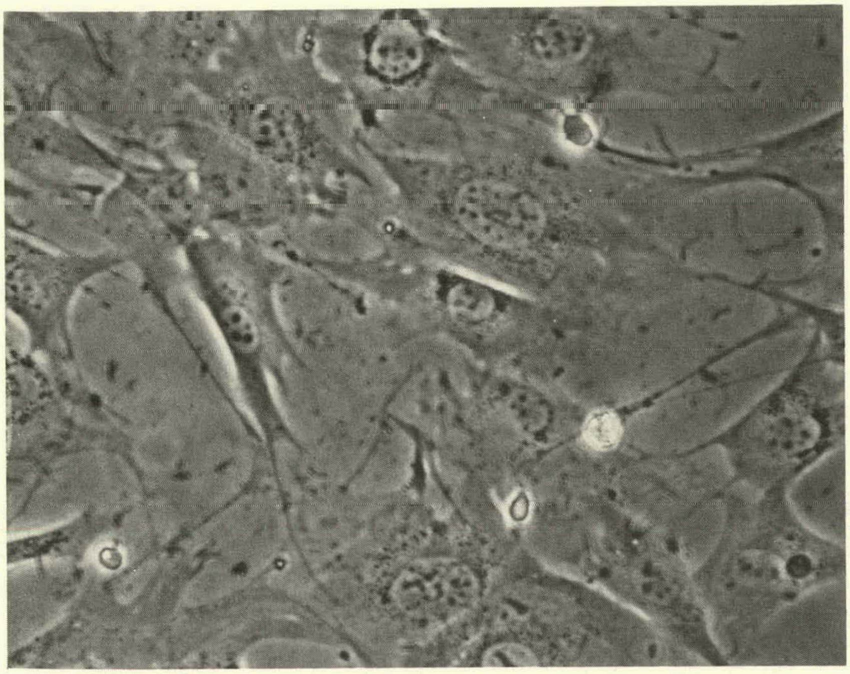

FIG. 4.--A phase contrast picture of the cells taken with the light microscope as they were irradiated.

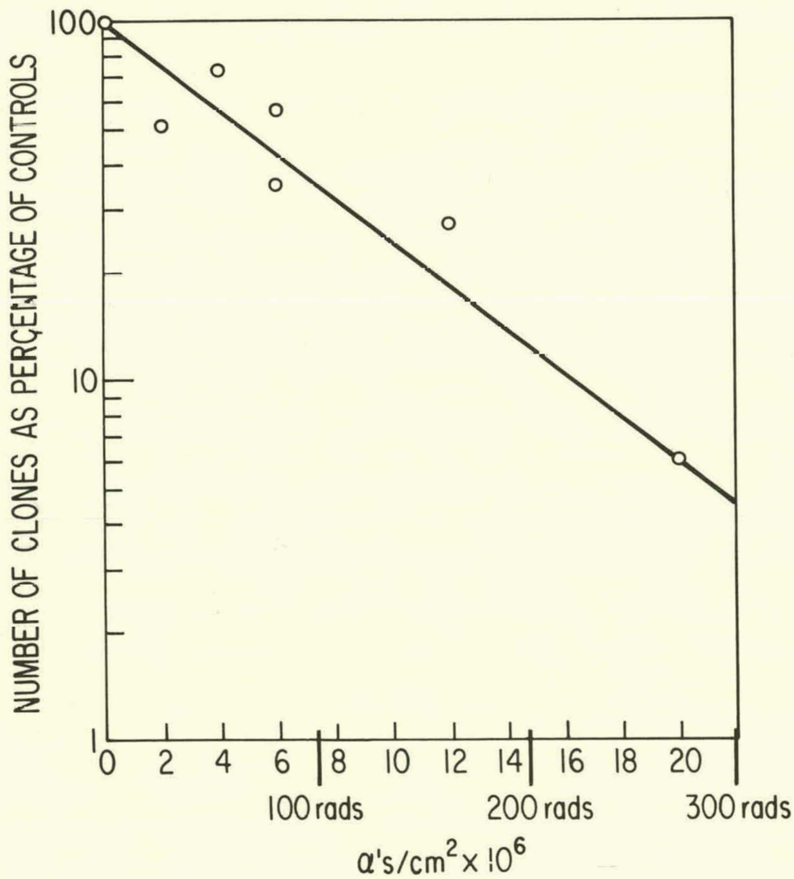

FIG. 5.--The number of cells surviving to form colonies expressed as a percentage of the number in the controls as a function of the radiation dose.

similar to those seen in Figure 2 the average thickness of the nuclei was found to be 2.2 μm. The cytoplasm covering the cell nuclei was often extremely thin and rarely exceeded one-quarter of the nuclear thickness. The cross-sectional areas of the flat aspect of the nuclei were determined by measuring 50 cells using the light microscope picture such as those seen in Figure 4, and were estimated to average 380 μm^2 (22 μm diameter) with variations of a factor of two or more. In the rounded state, the cross-sectional area was found to be about 100 μm^2.

Figure 5 shows the cell survival given as the number of clones found 10 to 14 days after irradiation, expressed as a percentage of the number of the controls. The amount of radiation is expressed both in terms of alpha particle fluence and the average dose in rad using an LET value of 85 keV/μm[10] for 5.6-MeV alpha particles. Since the cell thickness was so small (~ 3 μm) no correction was made for the loss of energy as the alpha particles passed through the cell layer. Examination of the alpha track plates which were placed in the same position as the cells confirmed not only the fluence of alpha particles in absolute numbers to within 10%, but also the uniformity of the beam to within 10%. In addition, the tracks seen on the plates showed that the alpha tracks passed through the 10-μm thick emulsion at right angles to the photographic plate, confirming the parallelism of the beam.

From Figure 5 it can be seen that the survival curve can be described by a single exponential within the limits of the experiment with a D_0 value (37% survival) corresponding to an alpha particle fluence of 7×10^6 alphas/cm^2 (96 rad). The reciprocal of this value, 14 μm^2, corresponds to the effective cross section for cell killing. Expressed in another way, this says that under the conditions of irradiation, 27 alpha particles, on an average, pass through the nucleus to produce cell killing. The numbers given here refer to a single experiment which is one of three which were averaged and reported elsewhere.[11] The values appear to depend in an interesting way on the passage number of the cell lines, a finding that will be explored in subsequent experiments.

Discussion

The experimental points shown in the survival curve (log scale) are fitted with a straight line in Figure 5. This appears to be the best fit within the experimental error of the results. The results are consistent with those found by other workers,[12] both in the fact that the survival is described by a single exponential and that the D_0 value is approximately the same as that found by others for alpha particles of similar energy. If we assume linearity, then we can determine the effective cross section for cell killing. This value (14 μm^2) represents about 4% of the cross section of the nucleus.

Although survival curves alone are insufficient to define the biological mechanisms,[5,10] one can consider which mechanisms are consistent with the results. In target theory, a straight line survival curve is consistent with a single alpha particle hitting a sensitive area whose dimensions are coincident with the effective cross-sectional area, provided the energy in each track is sufficient for maximal effect.

In the experiment described here, the direct field of influence of an alpha particle is geometrically well-defined because of the large target area presented by the cell to the parallel beam. It is not possible from these results alone to conclude where the sensitive site is located, but it has already been shown[13] that the nucleus is several orders of magnitude more sensitive for cell killing by alpha particles than is the cytoplasm. Hence, the most likely critical sites lie within the nucleus. In a recent paper, Datta et al.[14] have implicated the region just inside the nuclear membrane as the sensitive site; however, if this region were left intact and continuous under our conditions of irradiation, we might expect the cross-sectional area with our experimental design to be the whole nuclear area instead of 4% of this area which we found. It is noteworthy that the cross-sectional area found by Datta et al. for cell killing by 5.2-MeV alpha particles from polonium is 15 μm^2, a value almost identical with ours.

Usually the most prominent structures in the nuclei are undoubtedly the nucleoli. The nuclei of the cells studied here contained different numbers of nucleoli ranging from about 1 to 7, with an average number of 5. The cross-sectional area of all the nucleoli was estimated to be about 15% of the nuclear area; however, nucleoli are known to disappear during mitosis. Cells without nucleoli will not divide;[14] furthermore, the possibility that the nucleoli may be the critical site for inhibition of cell division is indicated by experiments in which uv microbeam irradiation of a single nucleolus (neuroplast of a grasshopper) at certain critical times (telophase to mid-prophase) was shown to inhibit mitosis permanently, whereas comparable irradiation of the surrounding areas of the cell did not.[15] Since the nucleoli are under the control of the nucleolar organizer, which at least in plants and some animal cells appears to be connected to chromatin material distributed throughout the nucleolus, a hit to only this portion of the nucleoli might be expected to interfere with the reproductive integrity of the cells. Although the nucleoli would appear attractive as the sensitive sites for cell killing, our results are insufficient to rule out other possible alternatives, such as the irradiation of chromatin material other than the nucleoli within the cell nucleus, as suggested by Dewey et al.,[16] or the production of double stranded breaks in nuclear DNA, which almost certainly occurs.

In the foregoing discussion we have endeavored to explain our results on the basis of the target theory because of the consistency of this particular theory with an exponential survival curve; however, as cautioned by Lea, in order to justify the target theory, it is advisable to irradiate with different doses, and if possible, with different types of radiation.

An experiment is now in progress using proton beams to irradiate the same cells using the same geometry. If the target theory holds, we would expect to find that the same number of protons as alpha particles are required for cell killing, provided the energy absorption is sufficient to be maximally effective. In this way, we should be able to confirm the area of the target which is sensitive for inhibiting mitosis if the target theory is applicable.

The fact that the target area for cell killing can no longer be considered to be the whole nucleus makes it easier to understnad how alpha particles can be so effective in producing carcinogenesis in vivo. If the sensitive sites for inhibition of cell reproduction and those reponsible for carcinogenic effects are different, as there is reason to believe,[17] then it is probable that different alpha particles acting at different sites are responsible for the different effects. Previously the fact that a single alpha particle hitting any part of the nucleus was considered to be effective in killing the cell made it difficult to explain how a cell could survive to become a cancer cell by the direct action of alpha particles on the nucleus. For this reason alternative indirect methods for the mechanism of carcinogenic action have been invoked.[2] Work currently in progress has shown that the cells used in this study can be transformed in vitro with alpha particles as has previously been shown possible using gamma irradiation[18] and different chemical agents.[17]

In conclusion, evidence is presented to suggest 1) that the nucleoli may be the important target site for inhibition of cell mitosis, although other alternatives cannot be ruled out, and 2) that the large number of alpha particles passing through the nucleus necessary for cell killing allows for the distinct possibility that the direct action of alpha particles on the nucleus may be the important event in carcinogenesis. In particular, this may be true for cells flattened against bone surfaces which are thought to be the cells at risk for osteosarcoma in patients carrying radium or plutonium burdens.

References

1. G. W. Barendsen, T. L. J. Beusker, A. J. Vergroesen, and L. Budke, Effects of different ionizing radiation on human cells in tissue culture, Radiat. Res. 13, 841–849 (1960).
2. D. M. Taylor, Actinide carcinogenesis: A direct or an indirect radiation effect?, Health Effects of Plutonium and Radium, W. S. S. Jee, Ed., The J. W. Press, Salt Lake City, Utah, pp. 681–690 (1976).
3. N. F. Kember, Some problems of microdosimetry with alpha emitters with particular reference to Americium-241, Proc. Int. Conf. on Radiation Damage in Bone, Oxford, April 10–14, 1960, Int. Atomic Energy Agency, Vienna, p. 29 (1960).
4. M. Goldman, An overview of high LET radiation effect in cells, The Health Effects of Plutonium and Radium, W. S. S. Jee, Ed., The J. W. Press, Salt Lake City, Utah, pp. 751–766 (1976).
5. M. M. Elkind and G. F. Whitmore, The Radiobiology of Cultured Mammalian Cells, Gordon and Breach Science Publishers, Inc., London (1967).
6. P. Todd, Possibilities for radiobiological and biomedical research with fast heavy ions, Proc. Int. Conf. on Heavy Ion Summer Study, Oak Ridge, June 12–July 1, 1972, S. T. Thorton, Ed., Nat. Tech. Inform.

Serv., Springfield, Virginia, pp. 491–509 (1972).
7. Catherine A. Reznikoff, David W. Brankow, and Charles Heidelberger, Establishment and characterization of a cloned line of C3H mouse embryo cells sensitive to postconfluence inhibition of division, Radiat. Res. 33, 3231–3238 (1973).
8. T. T. Puck and P. I. Marcus, A rapid method for viable cell titration and clone production with HeLa cells in tissue culture: The use of x-irradiated cells to supply conditioning factors, Proc. Nat. Acad. Sci. U.S. 41, 432–437 (1955).
9. W. H. J. Douglas, W. L. Whittle, and R. T. Dell'orco, Fine structural and cytochemical studies of human diploid fibroblasts arrested in an essentially nonmitotic state, In Vitro 12 (1), 74–82 (1976).
10. D. E. Lea, Actions of Radiations on Living Cells, 2nd Ed., University Press, Cambridge, pp. 303–304 (1955).
11. E. L. Lloyd, M. A. Gemmell, C. B. Henning, D. S. Gemmell, and B. J. Zabransky, Cell survival following alpha irradiation: Implications for carcinogenesis, Argonne National Laboratory, submitted for publication.
12. G. W. Barendsen, H. M. D. Walter, J. F. Flower, and D. K. Bewley, Effects of different ionizing radiations on human cells in tissue culture. III. Experiments with cyclotron-accelerated alpha particles and deuterons, Radiat. Res. 18, 106–119 (1963).
13. T. R. Munro, The relative radiosensitivity of the nucleus and cytoplasm of Chinese hamster fibroblasts, Radiat. Res. 42, 451–470 (1970).
14. Ratna Datta, Arthur Cole, and Sandra Robinson, Use of track-end alpha particles from ^{241}Am to study radiosensitive sites in CHO cells, Radiat. Res. 139–151 (1976).
15. Mary Esther Gaulden and Robert P. Perry, Influence of the nucleolus on mitosis as revealed by ultraviolet microbeam irradiation, Nat. Acad. Sci. Proc. 44, pp. 553–559 (1958).
16. W. C. Dewey, J. S. Noel, and C. M. Dettor, Changes in radiosensitivity and dispersion of chromatin during the cell cycle of synchronous Chinese hamster cells, Radiat. Res. 52, 373–394 (1972).
17. Catherine A. Reznikoff, John S. Bertram, David W. Brankow, and Charles Heidelberger, Quantitative and qualitative studies of chemical transformation of clones C3H mouse embryo cells sensitive to postconfluence inhibition of cell division, Cancer Res. 33, 3239–3249 (1973).
18. Margaret Terzaghi and John B. Little, X-radiation-induced transformation in a C3H mouse embryo derived cell line, Cancer Res. 36, 1367–1374 (1976).

ELECTRON MICROSCOPE STUDIES OF VIRUSES IN TUMORS INDUCED BY ^{239}Pu IN MICE

E. L. Lloyd and J. F. Loutit*

Tumors induced by the intraperitoneal injection of 100 nCi, 30 nCi, and 10 nCi of ^{239}Pu-citrate into male and female CBA mice were examined with the electron microscope for the presence of viruses. The tumors examined included 14 osteosarcomas, 2 lymphomas, 1 carcinoma, 1 haemangiosarcoma, and 1 reticulum-cell sarcoma. C-type viruses were positively identified in all the tumors examined with the exception of 3. In one of the exceptions, a lymphoma in a lymph node, suspicious virus-like particles were observed; in the other two, an osteosarcoma and a carcinoma of the lung from the same animal, there was no evidence of viral particles. In addition, no viruses could be detected in three samples of normal tissue. Despite the presence of virus in tumor and not in normal tissue, evidence from ongoing research is presented to suggest that the virus is merely a passenger.

Introduction

The best documented evidence of the hazards of bone-seeking radionuclides is related to those persons who were exposed to isotopes of radium. However, the bone-seeking element of greatest concern to the public at present is plutonium because of its increasing use in the nuclear industry. Although plutonium and radium both deposit in bone, their patterns of deposition are different.

The work described here was part of an experiment designed to study the effects of plutonium and to compare these with effects from radium carried out in a similar experiment with CBA and C3H mice.[1] The specific questions which this portion of the work was designed to answer were (1) Are viruses present in ^{239}Pu-induced tumors? (2) If so, are these viruses the same as those seen in the ^{226}Ra-induced tumors? (3) Do the viruses in different histological types of tumor appear to be the same? (4) Does sex affect the viral status? (5) Can viruses be seen in normal tissues taken from the same animals? All of these questions are, of course, secondary to the main question, "Is a virus the aetiological agent in the production of the tumors?"

*MRC Radiobiology Unit, Harwell, Didcot, Berks OX11 0RD, England.

Methods and Materials

Sixty mice (30 males and 30 females) of the CBA strain were injected intraperitoneally with three different doses of ^{239}Pu citrate to give 10 mice in each dose and sex group. The doses used were 100 nCi, 30 nCi, and 10 nCi. In addition, 40 chimeras (20 males and 20 females), CBA T6.T6/A mice, were injected with the highest dose, 100 nCi of plutonium. Radiation chimeras were produced by giving the host mice (CBA T6.T6/A) 1000 rad x rays when the mice were two months old and restoring the animals with fetal liver and lymphocytes from compatible donors (strain A) and (CBA T6.T6 × A) F_1 respectively. Plutonium was injected intraperitoneally one month later when the animals were stabilized. When bone tumors occurred in chimeras they could be typed for origin by passage to animals of the host or donor strains and the F_1 hybrid or analyzed for the presence or absence of the marker to determine whether or not the tumors originated from host's or donor's cells. All mice were 3 months old at the time of injection, and were injected on the same day. The animals were maintained until they either developed a tumor, when they were killed within a few days, or died of other causes. Autopsy was performed on all animals. In those that were killed with tumors large enough for sampling these tumors were examined at once by cryostat section and a small portion was assigned for study with the electron microscope.

Electron Microscope Technique

The samples used for electron microscope studies were fixed in glutaraldehyde and postfixed in osmium. Subsequently they were stained with uranyl acetate and lead citrate and examined in the Siemens-type 1A electron microscope. Details of the method have already been published.[1]

Results

Table 1 lists the viral status of the tumor tissues that were examined from the animals injected with the three different doses. In the osteosarcomas taken from the chimeras (CBA T6.T6/A) which were injected with 100 nCi ^{239}Pu more viruses were seen than in any of the other tissues examined. In 16 out

Table 1. Viral status of ^{239}Pu-induced tumors.

Dose	Strain	Sex	ANL No.	Tumor type	Site of tumor	Time of appearance (months)	Virus present or absent
100 nCi	Chimeras CBA T6.T6/A	Male	T37	Osteo	Sacrum	11	+
		Female	T34	Haemangio sarcoma	Sacrum	9	+
			T38	Osteo	Sacrum	12	+
	CBA	Male	T29	Lymphoma	Lymph node	7	+
			T43	Osteo	R. Illium	14	+
				Osteo	Th. vertebra 12		+
		Female	T25	Lymphoma	Lymph node	6	-?
			T40	Osteo	Ischio Pubis	12	+
			T49	Osteo	Humerus	16	+
30 nCi	CBA	Male	T43	Osteo	Lumbar vertebra 5	15	+
			T54	Osteo	Patella	17	+
		Female	T55	Osteo	Parosteal to humerus	17	+
			T64	Osteo	Cranium	23	+
			T66	Osteo	Sacrum	24	+
			T70	Osteo	Sacrum	25	+
			T74	Osteo	Scapula	26	+
10 nCi	CBA	Female	T47	Reticulum-cell sarcoma	Liver	15	+
			T85	Osteo	Rib	32	-
				Carcinoma	Lung		-

of 19 tumors examined, virus was demonstrably present. Suspicious virus-like particles were observed in one other tumor, while no virus was observed in either of the two tumors examined from animal T85. Figure 1 shows an electron micrograph demonstrating the typical C-type particles which were observed. The viruses were commonly found either lying with cytoplasmic vesicles or budding from endoplasmic reticulum associated with degenerate cells. No difference could be seen in the morphology or the frequency with which viruses were observed in samples taken from different tumor types or animals of different sex. The particles also appear identical to those which were observed in osteosarcomas from the CBA animals injected with ^{226}Ra [1] but different from those taken from the mammary tumors in the C3H animals.[1]

In the present series none of the normal tissue taken from the ribs of three of the CBA tumor-bearing animals showed any evidence of virus even after an extensive search.

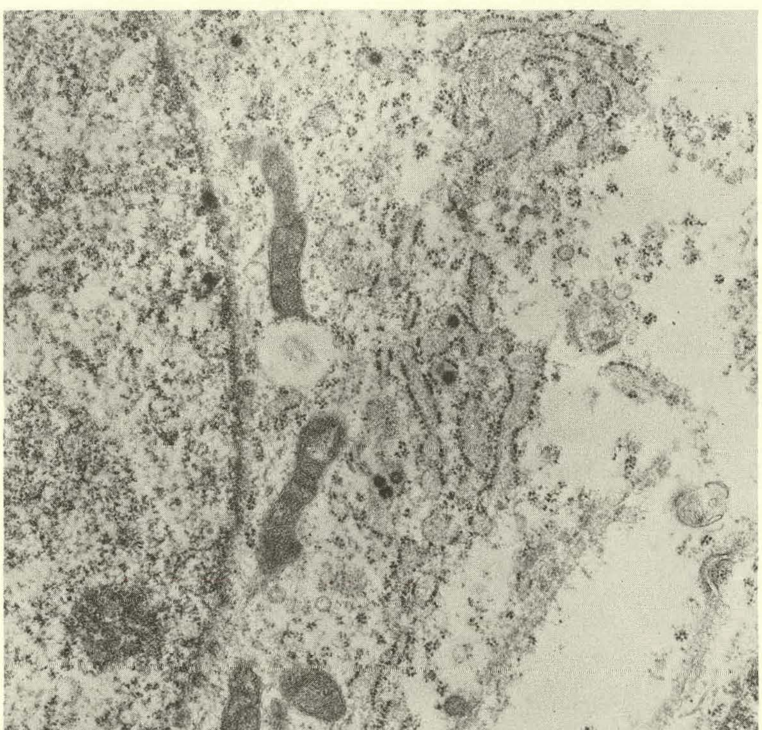

FIG. 1.--Electron micrograph of a portion of tissue taken from an osteosarcoma (T49) showing viruses lying within cytoplasmic vesicles or budding from the endoplasmic reticulum in a degenerate cell (× 35,000).

Discussion

Although virus was seen in most of the tumor tissue and none was observed in samples taken from normal bone, this does not allow us to implicate the virus as the aetiological agent. The tumor tissue may merely provide a favorable environment in which the virus can replicate sufficiently well to be above the threshold of detection by the electron microscope. Three lines of evidence from current work in progress indicate that viral action need not be involved in tumorigenesis: (1) Animals subjected to a procedure of immunization with homogenates of tumor tissue and subsequently injected with ^{226}Ra develop osteosarcoma to about the same extent and in the same time as unimmunized controls. (2) A single alpha particle directly hitting the nucleus may be insufficient to kill the cell,[2] contrary to what has been previously supposed. Hence, the survival of the cell with alteration of its DNA leading to malignancy is very probable as the result of a direct hit on the nucleus, without the intervention of a virus. (3) Cells irradiated in culture with alpha particles have been transformed in the same way, as has been shown by other workers using γ-irradiation[3] and chemical agents,[4] where no viruses nor viral products could be detected.

References

1. E. L. Lloyd, J. F. Loutit, and F. Mackevicius, Viruses in osteosarcomas induced by ^{226}Ra. A study of the induction of bone tumors in mice, Int. J. Radiat. Biol. 28 (1), 13–33 (1975).
2. E. L. Lloyd, M. A. Gemmell, C. B. Henning, D. S. Gemmell, and B. J. Zabransky, Cell survival following alpha irradiation: Critical sites and implications for carcinogenesis, this report.
3. M. Terzaghi and J. B. Little, X-radiation-induced transformation in a C3H mouse embryo derived cell line, Cancer Res. 36, 1367–1374 (1976).
4. C. A. Reznikoff, J. S. Bertram, D. W. Brankow, and C. Heidelberger, Quantitative and qualitative studies of chemical transformation of cloned C3H mouse embryo cells sensitive to postconfluence inhibition of cell division, Cancer Res. 33, 3239–3249 (1973).

HAZARD PLOTTING AND ESTIMATES FOR THE TUMOR RATE AND THE TUMOR GROWTH TIME FOR RADIOGENIC OSTEOSARCOMAS IN MAN

Peter G. Groer and John H. Marshall

The tumor rate (hazard rate) and the tumor growth time were estimated from a multiply censored sample of observed tumor appearance times in persons with an initial intake of ^{226}Ra and ^{228}Ra larger than about 230 μCi/kg bone. The tumor appearance times in these individuals appear to be exponentially distributed and follow, therefore, a straight line if plotted against the cumulative hazard on linear paper, the hazard paper for an exponential failure time distribution. This implies a constant dose independent tumor rate for osteosarcoma induction in the limit of large radiation doses. An expression for tumor rate from a stochastic model, described earlier in detail, showing this behavior, is discussed briefly.

Introduction

The method of hazard plotting developed to analyze failure for quality control purposes[1] is applied to the problem of estimating tumor rate (i.e., the hazard rate in statistical terminology) and the time of tumor growth from a censored sample of osteosarcoma appearance times (i.e., the time from the first exposure to intake to diagnosis) in humans with initial intakes greater than 230 μCi/kg skeleton. We chose these cases because we expected the tumor rate to be approximately independent of the initial radium intake and the time since first intake for large intake levels.[2] In addition, we use analytical procedures[3–5] which give estimators for the tumor rate and the tumor growth time. On linear graph paper these estimators completely determine a straight line, which represents a maximum likelihood fit to the data. A good fit of the hazard plot to this straight line verifies the constancy of the tumor rate. By proper design of a graph paper, this method of the hazard plot could be extended to time varying tumor rates.

The Hazard Plot

The hazard plotting method evaluates the tumor rate at the times of occurrence of the event of interest and not at arbitrary predetermined times. It uses, therefore, the maximum information contained in the sample. To obtain a hazard plot one calculates the ratio $1/a_1$, where a_1 is the number of cases at risk at t_1, the first observed tumor appearance time. The case in which an osteosarcoma has just been diagnosed is included in a_1. Then one proceeds to the next larger tumor appearance time t_2 and forms $1/a_2$, where a_2 is the number of cases at risk at t_2, i.e., $a_2 = a_1$ − (case with osteosarcoma at t_1 + number of cases censored between t_1 and t_2). The term censored means that the information of interest is not available. Reasons for censoring include: death from other causes, lost from the study, and still alive without tumor at the end of the study period (12/31/74). One continues in this fashion and calculates $1/a_i$ for each observed tumor appearance t_i. After completion of this procedure, one plots on linear graph paper the points $(1/a_1, t_1)$, $(1/a_1 + 1/a_2, t_2)$.... The first number, the abscissa, is the cumulative hazard, the second number of each pair, the ordinate, is the observed tumor appearance time. A hazard plot for the observed tumor appearance and censoring times (see Table 1) is shown in Figure 1. Since the plotted cumulative hazard function is reasonably straight, one could fit a straight line through the data points. The slope of this straight line is the tumor rate, the y-intercept for $x = 0$ corresponds to the tumor growth period. However, we chose to calculate these quantities with analytical methods for greater precision. This is explained in the subsequent section.

Estimation of tho Tumor Rate and the Tumor Growth Time

Estimators for the location and the scale parameter of the two parameter exponential distribution for single state, Type II censoring, were given by Epstein.[3] Cohen[4,5] pointed out that for the one parameter exponential distribution the estimators derived for Type II censoring provide approximate estimators for samples censored by random causes. We are making a similar approximation for the two parameter exponential distribution. The censoring of the sample of tumor appearance times considered here can be described as a combination of random and Type I censoring. The straightness of the hazard plot described in the previous section and shown in Figure 1 suggests that the sample was taken from an exponential distribution. This is also consistent with the stochastic model for osteosarcoma induction published in an earlier report.[2]

Table 1. Observed tumor appearance and censoring times (time of death due to causes other than osteosarcomas) after first intake of ^{226}Ra and ^{228}Ra for individuals with a total intake larger than 230 μCi/kg bone.

Initial intake ^{226}Ra + ^{228}Ra (μCi/kg bone)	Number of cases (and number of osteosarcomas)	Censoring time after first intake (yr)	Time of diagnosis of osteosarcoma after first intake (yr)
230.6 – 323.9	18 (8)	5,8,19,25,27,30, 34,40,40,53	11,12,16,22,26, 29,34,35
323.9 – 455	16 (3)	6,7,12,13,15,17, 21,28,28,31,35, 39,41	7,13,13

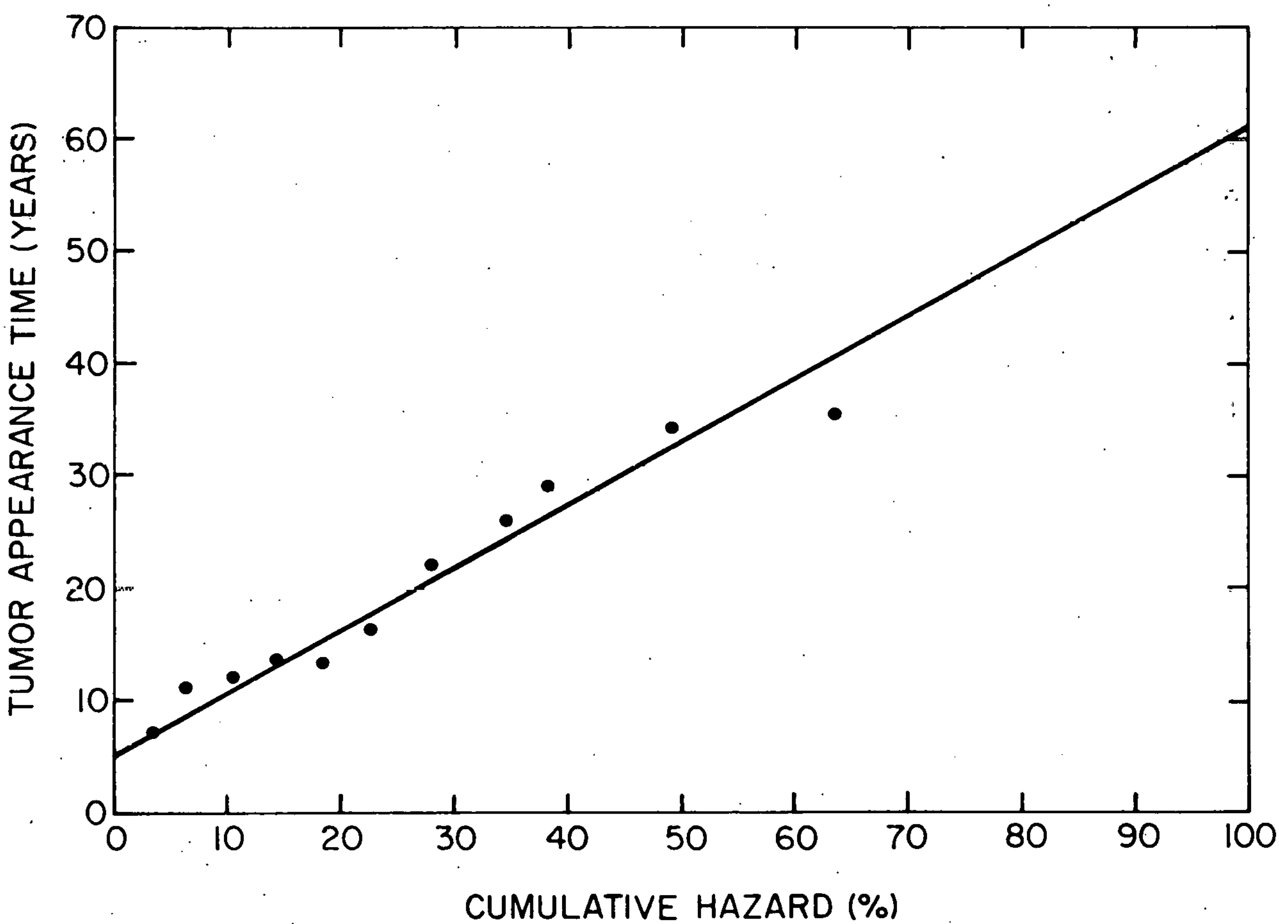

FIG. 1.--Hazard plot for tumor appearance times in individuals with initial intake of ^{226}Ra and ^{228}Ra larger than about 230 μCi/kg bone.

This model yielded the following expression for the tumor rate (hazard rate) as a function of dose:

$$\begin{aligned}
P(t) &= \theta^{-1}(1-(1+\kappa D(t-g))\exp(-\kappa D(t-g))) \\
\theta^{-1} &= \text{tumor rate } (\text{yr})^{-1} \text{ if } D \rightarrow \infty \\
g &= \text{tumor growth time (yr)} \\
D(t-g) &= \text{radiation dose at time } (t-g) \text{ to endosteal cells (rad)} \\
\kappa^{-1} &= \text{mean lethal } \alpha\text{-dose for endosteal cells } (\sim 100 \text{ rad})
\end{aligned} \tag{1}$$

θ is constant. Its dependence on cellular and physiological parameters was given earlier.[2] Expression 1 shows that P(t) reduces to a constant rate (θ^{-1}) in the limit of large radiation doses (doses much larger than $\kappa^{-1} = 100$ rad).

The estimators given by Epstein[3] to estimate g and θ are:

$$\begin{aligned}
\bar{g} &= t_1 - \bar{\theta}/n \\
\bar{\theta} &= T/(r-1)
\end{aligned}$$

t_1 = shortest tumor appearance time

T = total life (i.e., person-years at risk) observed between the shortest tumor appearance time and the end of the study period

n = number of individuals in the sample (34)

r = number of osteosarcomas in the sample (11). (2)

Using the data given in Table 1, one finds for $\bar{\theta}$ and $\bar{g}$:

$$\bar{\theta} - 55.7 \text{ yr}$$

$$\bar{g} = 5.4 \text{ yr} ,$$

consistent with the earlier analysis.[2] The bar means that the quantities are estimated. This estimate for θ implies a tumor rate of 1.8% $(\text{yr})^{-1}$ in the limit of large radiation doses. Approximate confidence intervals can easily be obtained for θ and g. To determine the confidence interval for θ one uses the fact[3] that $2(r-1)\bar{\theta}/\theta$ is distributed as $\chi^2(2r-2)$. One finds for the 95% confidence interval

$$32.6 \leq \theta \leq 116.2 .$$

For the confidence interval for g, one obtains, using formula 9 in Ref. 3

$$1.3 \leq g \leq 7 .$$

The lower bound implies that for an initial intake of ^{226}Ra and ^{228}Ra larger than about 230 μCi/kg bone one can be 95% confident that no osteosarcoma will appear before 1.3 yr after first intake. The cumulative hazard as a function of time after first intake corresponding to these estimates of g and θ is shown by the solid line in Figure 1.

It is interesting to apply the distribution of smallest values to the data in Table 1. Since tumor appearance times are exponentially distributed with parameter θ^{-1}, the smallest tumor appearance time in a sample of n = 11 should be distributed exponentially with an average rate of $n\theta^{-1}$ (about 1/5).[6] This implies that the appearance time of the first tumor, including growth time, will be on the average about 10 years after first intake in a sample of 11 tumors.

References

1. W. Nelson, Hazard Plotting for Incomplete Failure Data, J. Qual. Control Technol. 1, 27–52 (1969).
2. J. H. Marshall and P. G. Groer, Radiological and Environmental Research Division Annual Report, July 1974–June 1975, ANL-75-60, Part II, pp. 1–38.
3. B. Epstein, Estimation of the Parameters of two Parameter Exponential Distributions from Censored Samples, Technometrics 2, 402–406 (1960).
4. C. A. Cohen, Progressively Censored Samples in Life Testing, Technometrics 5, 327–339 (1963).
5. C. A. Cohen, Life Testing and Early Failure, Technometrics 8, 539–545 (1966).
6. E. J. Gumbel, Statistics of Extremes, Columbia University Press, New York (1958).

VARIANCE OF THE NUMBER OF TUMORS IN A MODEL FOR THE INDUCTION OF OSTEOSARCOMA BY ALPHA RADIATION

Peter G. Groer and John H. Marshall

An earlier report on a model for the induction of osteosarcoma by alpha radiation gave differential equations for the mean numbers of normal, transformed, and malignant cells. In this report we show that for a constant dose rate the variance of the number of cells at each stage and time is equal to the corresponding mean, so the numbers of tumors predicted by the model have a Poisson distribution about their mean values.

Introduction

In a previous report[1] we developed the following differential equations for the mean number of endosteal cells in different states ranging from normal to malignant:

$$\dot{\bar{m}}_1 = \sigma F s - \kappa F \bar{m}_1 - \sigma F \bar{m}_1$$
$$\dot{\bar{m}}_2 = \sigma F \bar{m}_1 - \kappa F \bar{m}_2 - \lambda \bar{m}_2$$
$$\dot{\bar{m}}_3 = \lambda \bar{m}_2 \quad . \qquad (1)$$

The differential equation for the probability distribution $P_{m_1 m_2 m_3}(t) = P_{000}$ of the number of cells in the different states is easily obtained.

$$\dot{P}_{000} = \sigma F s\, P_{-100} + \kappa F(m_1 + 1)\, P_{100} + F(m_1 + 1)\, P_{1-10}$$
$$- (\sigma F s + \kappa F m_1 + \sigma F m_1)\, P_{000} + \kappa F(m_2 + 1)\, P_{010}$$
$$+ \lambda(m_2 + 1)\, P_{01-1} - (\kappa F m_2 + \lambda m_2)\, P_{000} \quad . \qquad (2)$$

Equation 2 can be used to calculate the differential Eqs. 1 for the mean number of cells (first moment) and the differential equations for the different second order moments of the m_i's.

Derivation of the Variances of m_2 and m_3

For the second moments one finds the following equations:

$$\dot{\overline{m_1^2}} = \sigma F s - 2(\sigma F + \kappa F)\, \overline{m_1^2} + (2\sigma F s + \sigma F + \kappa F)\, \bar{m}_1$$

$$\dot{\overline{m_2^2}} = -2(\lambda+\kappa F)\,\overline{m_2^2} + 2\sigma F\,\overline{m_1 m_2} + \sigma F\bar{m}_1 + (\lambda+\kappa F)\,\bar{m}_2$$

$$\dot{\overline{m_3^2}} = -2(\lambda+\kappa F)\,\overline{m_2 m_3} + \lambda\,\bar{m}_2$$

$$\dot{\overline{m_1 m_2}} = -(\lambda+2\kappa F+\sigma F)\,\overline{m_1 m_2} + \sigma F s\bar{m}_2 + \sigma F s\bar{m}_2 + \sigma F(\overline{m_1^2} - \bar{m}_1)$$

$$\dot{\overline{m_1 m_3}} = -(\sigma F+\kappa F)\,\overline{m_1 m_3} + \sigma F s\bar{m}_3 + \lambda\overline{m_1 m_2}$$

$$\dot{\overline{m_2 m_3}} = -(\lambda+\kappa F)\,\overline{m_2 m_3} + \sigma F\,\overline{m_1 m_3} + \lambda(\overline{m_2^2} - \bar{m}_2)\ . \qquad (3)$$

The bar above the m_i's in Eq. 3 indicates average. The initial conditions for Eq. 3 are $\overline{m_i^k m_j^l} = 0$ for $t=0$ and $(k,l) = 0,1,2$ and $(i,j) = 1,2,3$. All coefficients (e.g., λ, σF) appearing in Eq. 3 are assumed to be constant. Therefore, all equations for the first and second moments could be solved explicitly. However, the calculations for the second moments are tedious. It turned out to be more convenient to determine the variances by looking at the structure of the differential equations. It is well known that the variance of m_1 is equal to $\bar{m}_1$, since this is just the result for an "immigration-death" process.[2] An easy derivation of this result and a useful demonstration of the technique used follows:

$$\mathrm{var}\,(m_1) \equiv \overline{m_1^2} - \bar{m}_1^2$$

$$\dot{\mathrm{var}}\,(m_1) = \dot{\overline{m_1^2}} - \dot{\overline{m}_1^2}\ . \qquad (4)$$

From Eq. 4 and $\dot{\overline{m_1^2}}$ in 3 follows:

$$\dot{\mathrm{var}}\,(m_1) + \dot{\bar{m}}_1 = 2(\sigma F s - (\kappa F + \sigma F)\ \mathrm{var}\,(m_1))\ . \qquad (5)$$

From Eq. 5 and $\dot{\bar{m}}_1$ in Eq. 1 follows by inspection:

$$\mathrm{var}\,(m_1) = \bar{m}_1\ . \qquad (6)$$

Identity 6 implies that m_1 has a Poisson distribution with a mean $\bar{m}_1(t)$. The variance of m_2 can be found in a very similar manner. From Eq. 4 with m_1

replaced by m_2 and $\dot{\overline{m_2^2}}$ in Eq. 3 follows:

$$\dot{\text{var}}\,(m_2) + \dot{\overline{m_2}} = 2(\sigma F\bar{m}_1 - (\lambda + \kappa F)\ \text{var}\,(m_2)) + $$

$$+ 2\sigma F\ \text{cov}\,(m_1 m_2)\ , \qquad (7)$$

where $\text{cov}\,(m_1 m_2) = \overline{m_1 m_2} - \bar{m}_1 \bar{m}_2$. To obtain var (m_2) from Eq. 7 the covariance of m_1 and m_2 has to be found. Using $\dot{\overline{m_1 m_2}}$ in Eqs. 3 and 6, $\dot{\bar{m}}_1$ and $\dot{\bar{m}}_2$ one finds:

$$\dot{\text{cov}}\,(m_1 m_2) = -(\lambda + 2\kappa F + \sigma F)\ \text{cov}\,(m_1 m_2)\ . \qquad (8)$$

Together with it's initial condition Eq. 8 implies cov $(m_1 m_2) = 0$ for all t, and

$$\text{var}\,(m_2) = \bar{m}_2 \qquad (9)$$

follows immediately from Eq. 7. Equation 9 shows that $m_2(t)$ has a Poisson distribution with mean $\bar{m}_2(t)$. For the variance of m_3 one finds the equation:

$$\dot{\text{var}}\,(m_3) = 2\lambda\ \text{cov}\,(m_2 m_3) + \lambda\bar{m}_2\ , \qquad (10)$$

again using Eq. 4 and $\dot{\overline{m_3^2}}$ from Eq. 3. As for var (m_2), the covariance term has to be evaluated. From Eq. 3 and the definition of cov $(m_2 m_3)$ follows:

$$\dot{\text{cov}}\,(m_2 m_3) = -(\lambda + \kappa F)\ \text{cov}\,(m_2 m_3) + \sigma F\ \text{cov}\,(m_1 m_3)\ . \qquad (11)$$

For the second term in Eq. 11

$$\dot{\text{cov}}\,(m_1 m_3) = -(\sigma F + \kappa F)\ \text{cov}\,(m_1 m_3) \qquad (12)$$

holds. This means cov $(m_1 m_3) = 0$ for all t because of the initial conditions and yields immediately cov $(m_2 m_3) = 0$ for all t for the same reason. This result and Eq. 10 give

$$\dot{\text{var}}\,(m_3) = \lambda\bar{m}_2\ . \qquad (13)$$

The immediate consequence of Eq. 13 and $\dot{\bar{m}}_3 = \lambda\bar{m}_2$ is of course var $(m_3) = \bar{m}_3$. Therefore, the number of tumors, m_3, has a Poisson distribution with mean $\bar{m}_3$.

<u>References</u>

1. J. H. Marshall and P. G. Groer, Radiological and Environmental Research Division Annual Report, July 1974-June 1975, ANL-75-60, Part II, pp. 1–38.

2. D. R. Cox and H. D. Miller, The Theory of Stochastic Processes, Methuen and Company Ltd., London, p. 168 (1965).

LONG-TERM EFFECTS OF RADIUM EXPOSURE IN FEMALE DIAL WORKERS: HEMATOCRIT AND BLOOD PRESSURE*

A. P. Polednak

Hematocrit and systolic and diastolic blood pressure were analyzed in women first employed as radium dial workers in 1913 to 1929 and in 1930 to 1954. Internal comparisons on these variables were made by dose group, using average skeletal dose estimated some years after exposure to radium. External comparisons were made using normative data from the U.S. National Health Survey. In women exposed from 1913 to 1929, an apparent long-term effect of high-dose radium exposure on hematocrit was evident. Statistically significant results were obtained using univariate and multivariate (multiple regression) analyses for women aged 65 to 84. The effect (i.e., lower hematocrit at higher doses) appeared to be greatest in the highest dose group, especially at 1000+ rad. It did not, however, involve a higher frequency of "low" hematocrit suggestive of anemia. No apparent effect of dose on blood pressure was evident in the women exposed in 1913 to 1929. In women exposed in 1930 to 1954, dose was a significant predictor of systolic blood pressure in 45- to 54-year olds, but not in the 55- to 64-year olds. Analysis of longitudinal data on these populations will be required.

*Summary of a paper to be published in Environmental Research.

ADULT HEIGHT AND WEIGHT OF FEMALE RADIUM DIAL PAINTERS, WITH ANALYSIS OF RADIATION EFFECT ON GROWTH*

A. P. Polednak

The relationship between exposure to internal radiation and adult height and weight was considered in a group of 556 females who worked as radium dial painters. These women were first exposed to radium at age 14 to 29 years, and height and weight were measured at age 46 to 80. Using univariate and multivariate (multiple regression) analysis, no significant overall effect of age at first exposure, or average skeletal dose, on height and weight was disclosed.

The possible effect of radiation on growth was assessed. Skeletal dose in rad received from first exposure to age 21 was estimated in a subgroup of females who were in the earliest birth cohort (1900 to 1909) and were 14 to 17 and 18 to 21 years old at first exposure. Height and weight were compared by dose group (0–9, 10–99, and 100+ rad). There was no evidence for an effect of dose on adult height, in agreement with findings on Japanese atomic bomb survivors exposed to external radiation at age 12 to 17 years. Mean height also did not differ between the two age-at-first exposure groups. These findings support the conclusion that older children may not be susceptible to long-term growth effects of exposure to various types of radiation. It is pointed out, however, that the present findings refer only to long-term survivors of radium exposure.

---

*Summary of a paper to be published in Human Biology.

PLUGGED HAVERSIAN CANALS AND SKELETAL DOSE IN RADIUM CASES*

David J. Simmons,† A. T. Keane, Richard B. Holtzman, and J. H. Marshall

Microscopic and radiological changes in the skeletons of 30 cases of radium poisoning (dial painters, chemists, and iatrogenic cases) were studied to determine the correlation with average skeletal dose from ^{226}Ra and ^{228}Ra. The raw data dealing with plugged canals were obtained from published studies[1–3] and from study of the bones of a case examined at ANL.[4] There was no significant correlation with age at exposure, age at death, or duration of radium intake. For 14 of the cases exposed predominantly to ^{226}Ra (initial body burden ratio ^{226}Ra/^{228}Ra > 4), cumulative rad (CR) and cumulative rad-yr (CRY) correlated about equally well ($r = 0.86$ and $r = 0.87$, respectively, $P < 0.01$). However, when all 30 cases were considered, including 14 cases exposed predominantly to ^{228}Ra (^{228}Ra/^{226}Ra > 1.8), the correlation coefficient between plugging and CRY was 0.81 ($P < 0.01$), while that with CR was only 0.48 ($P < 0.01$).

Plugging varied approximately as the square root of either CR or CRY within the range of doses observed (1 to 30 krad and 10 to 700 krad-yr). The expression, $\%\text{plugs} = (\text{CRY})^{0.56}$, where CRY is in krad-yr, fitted the data to within a factor of two in two-thirds of the cases. Plugging due to radium can probably not be detected below a CR of 1 krad or a CRY of 10 krad-yr because the normal incidence is of the order of 1%. Reduced x-ray score for these 30 cases also correlated with CRY ($r = 0.64$, $P < 0.01$), but not as well as did the plugged canals.

---

*Summary of a paper published in Health Physics 29, 767–775 (1975).

†Department of Surgery, Division of Orthopedic Surgery, Washington University School of Medicine, St. Louis, Mo. 63110.

References

1. R. E. Rowland, J. H. Marshall, and J. Jowsey, Radiat. Res. 10, 323 (1959).
2. D. L. Gunner and J. C. Fitzsimmons, Microradiographic studies. Radium and Mesothorium Poisoning, MIT Ann. Prog. Report, MIT-952-5, p. S-21 (1968).
3. O. Parizek, J. C. Fitzsimmons, and D. L. Gunner, Microradiographic study of the hypermineralization of haversian canals in bone samples from radium cases. Radium and Mesothorium Poisoning, MIT Ann. Prog. Report MIT-952-6, p. 82 (1969).
4. D. J. Simmons and R. B. Holtzman, Argonne National Laboratory Radiological Physics Division Annual Report, July 1970-June 1971, ANL-7860, Part II, p. 127.

CHROMOSOME ABERRATIONS IN THE PERIPHERAL LYMPHOCYTES OF THORIUM WORKERS WITH LOW BODY BURDENS OF ^{212}Bi

S. F. Hoegerman

Cytogenetic analysis of 8 thorium workers and 3 controls has not shown a significant elevation in the level of chromosome breakage in the workers' peripheral lymphocytes. This finding is consistent with an estimate of the amount of damage to be expected in these cases, based on the level of chromosome breakage observed in Thorotrast cases with measured ^{212}Bi burdens.

Introduction

Relatively little is known regarding the cytogenetic risk associated with industrial exposure to thorium. While there have been several studies of chromosome breakage in patients who received injections of Thorotrast (colloidal ThO_2) for contrast radiography,[1-4] there has been only one previous study of persons with industrial thorium exposure.

Costa-Ribiero et al.[5] studied a group of 67 Brazilians who were actively working in a monazite processing mill. Their results, summarized in Table 1, indicate that there is an increase in the level of chromosome breakage in the subjects who work in the relatively highly contaminated areas of the mill.

Table 1. Chromosome Breakage in Workers in a Brazilian Monazite Mill

Mean airborne ^{212}Pb level (pCi/1)	No. of workers	No. of cells	Dicentrics + rings per 100 cells	Deletions per 100 cells
0.900	30	2679	0.41	2.58
0.090	9	900	0	2.00
0.007	28	2430	0.08	0.91

Costa-Ribiero and coworkers attribute the increase in chromosome breakage in the more highly exposed workers to the radiation from ^{220}Rn and its daughters. They argue that the workers' exposure to radionuclides higher up the thorium decay chain is negligible since long-lived activity was rarely found in their air samples and, when found, was associated with monazite particles of such a large size that they were "not believed to be inhaled in large quantities, and, even if they were, they could not reach the lungs, being then eliminated through the esophagus and intestinal tract."

The largest series of Thorotrast cases for which both body burdens and chromosome aberration frequencies are known is that of Fischer et al.[1] The 19 patients in this series had an average ^{212}Bi burden in the upper abdominal region of 118 nCi. The frequency of dicentrics and rings per 100 peripheral lymphocytes averages 7.41 ± 5.64 per 100 nCi ^{212}Bi burden.

The 8 men in the present study were employees of an American thorium processing plant. Five cases had statistically significant ^{212}Bi burdens. These men began their employment in the industry between 1937 and 1946 and worked in it for an average of approximately 32 years. The 3 men whose burdens are not significantly greater than zero began their employment between 1957 and 1966 and worked for an average of approximately 7 years.

Materials and Methods

Peripheral lymphocytes were cultured by a modified Moorehead technique.[6] Our current procedure is as follows:

Eight to 10 ml of venous blood are drawn into a sterile heparinized vacutainer. The red blood cells (RBC's) are allowed to sediment, and 0.6 to 0.8 ml of the plasma-leucocyte fraction plus a small quantity of RBC's are cultured in a sterile tissue culture flask. Each flask contains 0.4 ml medium F 10, 1.0 ml fetal calf serum (both from Gibco), 0.1 ml reagent grade PHA (Wellcome-Burroughs), and 0.1 ml laboratory reagent grade penicillin-streptomycin mixture (Becton-Dickinson). The prepared medium is filtered through a 0.2-μm Nalgene filter prior to dispensing into the flasks. A minimum of 4 flasks are initiated for each patient.

Colcemid (0.3 ml, 10 μg/ml) is added to each flask 45 hr after addition of the sample. Three hours later, the cell suspension is transferred to a centrifuge tube, centrifuged at 125 _g_ for 15 min, and the pellet is resuspended in 5 ml of 0.075 _M_ KCl. After 7 min, the tubes are centrifuged at 50 _g_ for 7 min, and the pellet is resuspended in the fixative (3:1 methanol:glacial acetic acid). The cells remain in the first fixative for a minimum of 10 min. They are then centrifuged (50 _g_ for 10 min) and resuspended in fresh fixative.

Slides are prepared by spreading the cells on cold, wet slides. The slides are quickly flamed and air dried and are then stained for 5 min in 5% Giemsa stain.

The slides are scanned, and cells with at least 46 centromeres are scored for aberrations. All cells are scored for both stable and unstable chromosome aberrations, chromatid aberrations, and ploidy. To check for stable chromosome rearrangements, all chromosomes are karyotyped to major chromosome group by direct observation through the microscope.

One hundred cells were scored for each of the 8 thorium workers and each of the 3 adult male controls. Slides were coded and scored without knowledge of the workers' body burdens.

Results

The body burdens of the thorium workers, along with data on unstable chromosome aberrations, chromatid aberrations, and the frequency of hyperdiploid cells in both thorium workers and controls, are given in Table 2. No cells with translocations of inversions were scored in either worker or control slides. An inversion was observed in a cell from case L-4317, but this cell was not included in the sample since it contained only 45 chromosomes.

Two of the thorium workers had stable deleted chromosomes in all of their cells that were examined. Case L-0809 has a Y chromosome with a deleted long arm. A karyotype of this case is shown in Figure 1. A comparison of the G-group chromosomes of this case with the G-group chromosomes of controls is shown in Figure 2.

The second case (L-1330) has a deletion of the entire short arm of a D-group chromosome. A complete karyotype of this case is shown in Figure 3. Trypsin-Giemsa banding established that the deleted chromosome is a member of the number-14 pair. Figure 4 is a banded partial karyotype of this case.

Table 2. Cytogenetic Abnormalities in Thorium Workers and Controls

	Case No.	^{212}Bi body burdens (nCi)	Chromosome aberrations in 100 cells: Dicentrics	Rings and minutes	Terminal deletions	Chromatid aberrations in 100 cells: Deletions	Gaps	Hyperdiploid cells in 100 cells
Thorium workers	L-1167	3.49 ± 0.35	0	0	1	0	0	2
	L-1101	2.14 ± 0.28	0	0	0	0	0	0
	L-4317	1.49 ± 0.36	1	0	0	0	1	2
	L-0809	0.73 ± 0.22	0	0	0	0	1	0
	L-1330	0.53 ± 0.19	0	0	0	1	0	1
	L-2076	0.00 ± 0.31	0	0	0	1	2	1
	L-0591	0.02 ± 0.28	0	0	0	0	3	0
	L-1328	-0.10 ± 0.20	0	0	1	0	2	2
Controls	50-016	-	0	0	0	0	1	1
	50-128	-	0	0	0	2	3	0
	50-129	-	0	0	1	0	1	0

Discussions and Conclusions

In the absence of quantitative data on the relevant anatomical distribution of lymphocytes and on both the anatomical and isotopic distribution of radionuclides in the thorium workers, it is impossible to calculate the average dose received by the cells at risk. One can, however, compare the aberration level found in our population with that found in Thorotrast-burdened patients by Fischer et al.[1]

The average ^{212}Bi burden of the 5 thorium workers with a statistically significant burden is 1.68 nCi (provisional best estimate pending final calibration of the counting equipment). Extrapolating from Fischer's results to the thorium workers, we would expect a dicentric plus ring frequency of

$$\frac{1.68\ (7.41 \pm 5.64)}{100} = 0.124 \pm 0.095/100 \text{ cells}$$
$$= 0.62 \pm 0.48/500 \text{ cells} .$$

One dicentric was scored in our sample of 500 cells. The agreement between the observed and expected aberration frequency is probably fortuitous. The expected aberration level may be a highly inaccurate estimate of the amount of cytogenetic damage to be anticipated in thorium workers since the majority of these men's burdens is probably deposited on pulmonary surfaces and/or in

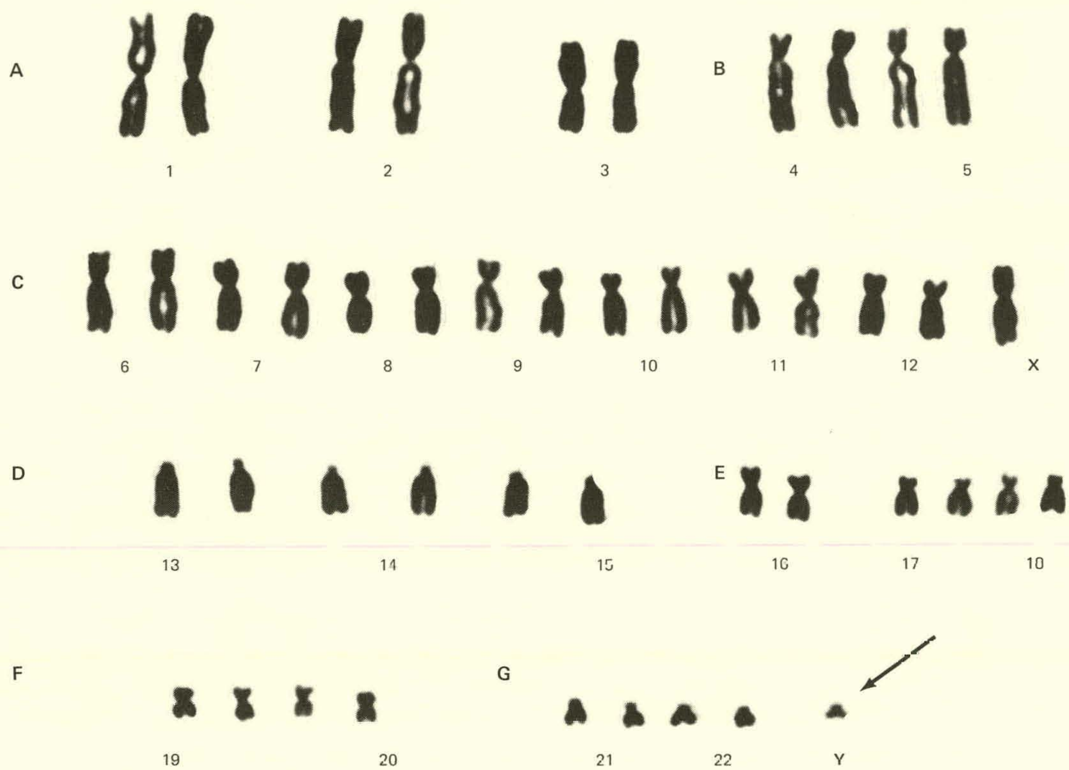

FIG. 1.--Karyotype of case L-0809. Note the short Y chromosome.

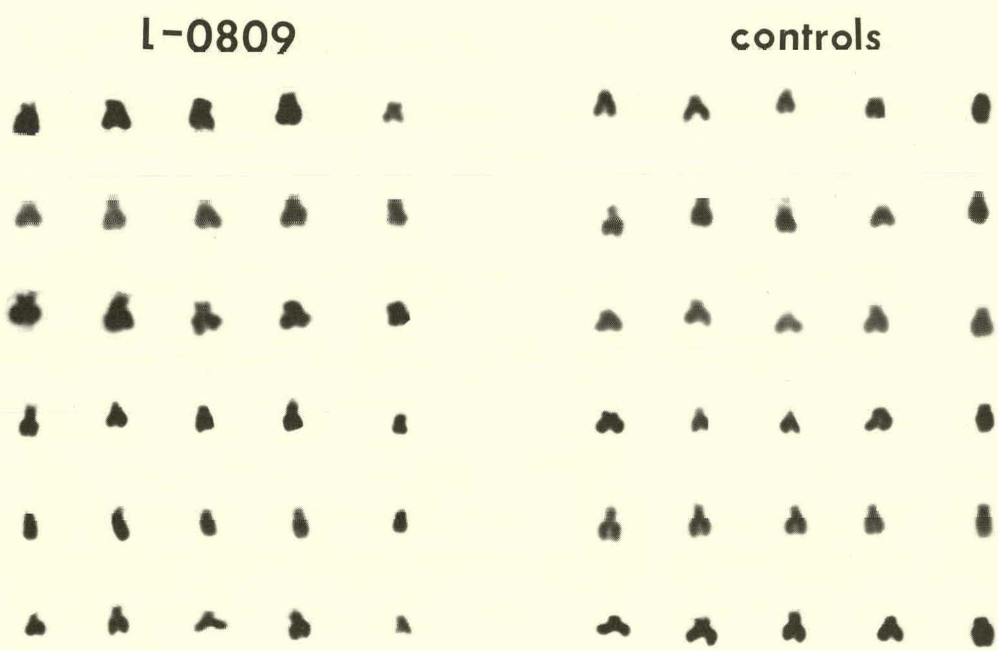

FIG. 2.--Comparison of the G-group and Y chromosomes of case L-0809 with those of controls. The Y chromosomes are shown in the right-most columns.

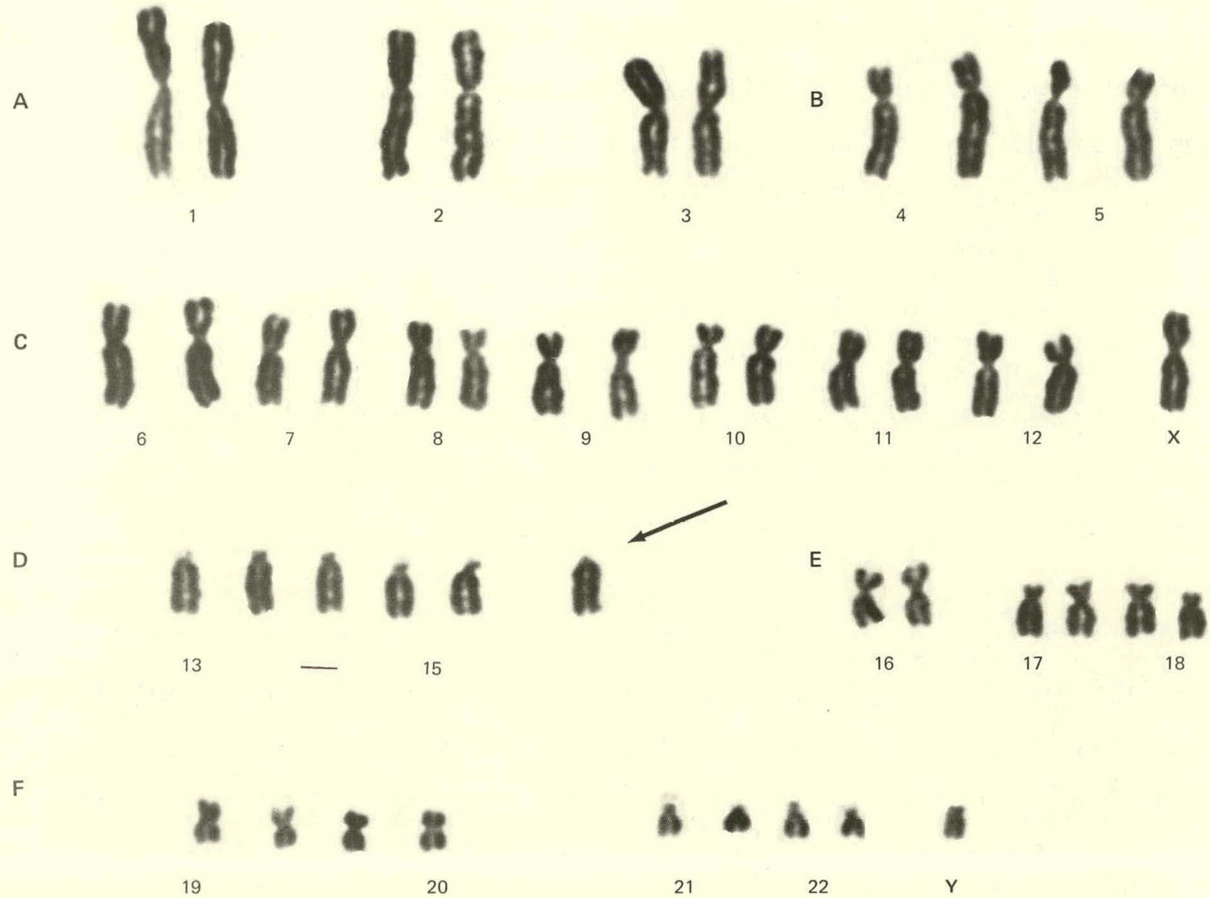

FIG. 3.--Karyotype of case L-1330. Note the absence of the short arm on a D-group chromosome.

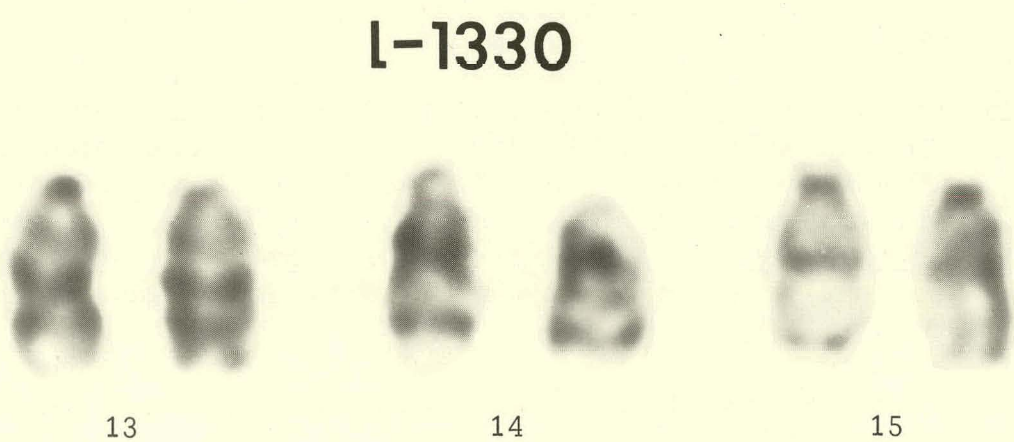

FIG. 4.--Trypsin-Giemsa banded D-group chromosomes of case L-1330. Note that the deleted chromosome is one of the number 14 pair.

tracheobronchial lymph nodes. Thorotrast cases generally have a high percentage of their burden deposited in liver and spleen, organs that contain high concentrations of lymphocytes. The average dose to lymphocytes per nCi of ^{212}Bi may be significantly different in our cases because of differences in the ^{221}Bi/^{232}Th ratio and differences in the anatomical distribution of ^{232}Th and its daughter products.

It is probable that the variant Y chromosome and the deleted chromosome 14 found in two of the thorium cases were not radiation induced. The length of the Y chromosome varies between individuals, and variant Y chromosomes of unusual size are frequently unaccompanied by phenotypic effect.[7] While the deleted chromosome 14 is not a common variant, we can argue that the deletion of its short arm would not be expected to have a phenotypic effect. Individuals with 45 chromosomes including a D/D or D/G Robertsonian translocation lack the short arms of two acrocentric chromosomes and are phenotypically normal.[7] The possibility that these atypical chromosomes were radiation induced cannot be entirely discounted. Buckton et al.[2] found two cases with definite mosaicism for stable chromosome rearrangements in two of 36 Thorotrast cases. A suggestion of possible mosaicism was noted for three additional cases. Cytogenetic analysis of other tissues from our patients or from the male progeny of the patient with the variant chromosome would, therefore, be required to establish firmly that their atypical chromosomes were not radiation induced.

References

1. P. Fischer, E. Golob, E. Kunze-Mühl, A. Ben-Haim, R. A. Dudley, T. Müllner, R. M. Parr, and H. Vetter, Chromosome aberrations in peripheral blood cells in man following chronic irradiation from internal deposits of Thorotrast, Radiat. Res. 29, 505–515 (1966).
2. K. E. Buckton, A. O. Langlands, and G. E. Woodcock, Cytogenetic changes following Thorotrast administration, Int. J. Radiat. Biol. 12, 565–577 (1967).
3. W. Kemmer, H. Muth, F. Tranekjer, and L. Edelmann, Dose dependence of the chromosome aberration rate in Thorotrast patients, Biophysik 7, 342–351 (1971).
4. H. J. Woodliff, G. Cohen, and W. Gallon, Chromosome aberrations in lymphocytes from patients exposed to thorium dioxide, Med. J. Australia 2, 768–771 (1972).

5. C. Costa-Ribiero, M. A. Barcinski, N. Figueiredo, N. Penna-Franka, N. Lobao, and H. Krieger, Radiobiological aspects and radiation levels associated with the milling of monazite sand, Health Phys. 28, 225–231 (1975).
6. P. S. Moorehead, P. C. Nowell, W. J. Mellman, D. M. Battips, and D. A. Hungerford, Chromosome preparations of leukocytes cultured from human peripheral blood, Exp. Cell Res. 20, 613–616 (1960).
7. H. Levine, Clinical Cytogenetics, Little, Brown and Co., Boston (1971).

GROSS DISTRIBUTION OF ^{226}Ra IN MAN FROM EXTERNAL COUNTING*

J. Rundo, M. A. Essling, and D. R. Huff

When the first γ-ray measurements of a radium patient's body radioactivity indicate a content in excess of about 20 nCi of ^{214}Bi (RaC), a "7-position scan" is made. Measurements are made with two detectors, above and below the supine subject, at seven equally spaced positions along the length. The spacing is set at 15% of the subject's height. Such scans have been made for 40 different patients, and although the detectors are uncollimated, a surprising amount of information on the distribution is revealed.

In general, the distribution could be assigned fairly unambiguously to one of four categories. In Category I (18 cases) a clear maximum of activity was observed in the lowest third of the body. Category II (12 cases) was the reverse; the highest counting-rate was observed from the uppermost third of the body. Rough symmetry of activity distribution down the length of the body was seen in the other two categories. In Category III (7 cases) the counting-rate was at a maximum near the middle of the body, while it was at a minimum for Category IV (3 cases). There was considerable variability within any one category, and no correlation between body content of radium, or mode of intake, and category. In seven cases of bone sarcoma (including four examined by Miller[1]) the site of malignancy failed to correspond with the region of highest observed activity. Furthermore, of eleven cases of carcinoma of the mastoid (including seven examined by Miller), only three were in Category II (highest activity in or near the head) while six were in Category I; there was one case in each of Categories III and IV. If eleven subjects were chosen at random from our 40 cases, we should expect three cases to be in Category II and five in Category I. Thus the information on the gross distribution of radium in the body is of no value in predicting the possible site of a malignancy.

---

*Summary of paper published in The Health Effects of Plutonium and Radium, W. S. S. Jee, Ed., The J. W. Press, Salt Lake City, pp. 409–420 (1976).

Reference

1. C. E. Miller, Distribution of radium in humans, Health Division Gamma-Ray Spectroscopy Group Semiannual Report, January-June 1964, ANL-6839, pp. 18–39.

THE MACRODISTRIBUTION OF ^{226}Ra IN THE SKELETON OF A RADIUM DIAL PAINTER*

R. B. Holtzman and D. J. Simmons†

The concentrations of ^{226}Ra were determined in 190 samples of bone and in four teeth from a woman (Case 01-183) who had worked for two years as a radium dial painter 52 years prior to her death. The terminal body content of ^{226}Ra was 200 nCi. The weighted mean concentration of activity in bone was 146 ± 11 pCi/g ash, with a range of 12 to 1000 pCi/g ash. The mean level in cortical bone was 116 ± 14 pCi/g ash, while that in porous bone (trabecular and eroded cortex) was 227 ± 25 pCi/g ash.

The concentrations of the ^{226}Ra in long bones were fairly constant along the shafts and increased greatly toward the ends. The concentration patterns were generally symmetrical with respect to right and left sides. The patterns in bone from the lower limbs (femur, tibia, and fibula) were similar to each other but differed from those in the upper limbs (humerus and radius). For rib the mean concentration of 107 pCi/g ash was consistent with a uniformly distributed 200-nCi skeletal content. The concentrations in the left ribs were similar to those in the right. The levels in the vertebrae (40 ± 12 pCi/g ash) were, in the main, lower than those in the ribs and varied widely with location.

---

*Summary of a paper presented at The Workshop on the Biological Effects and Toxicity of ^{239}Pu and ^{226}Ra at Sun Valley, Idaho, October 5–10, 1975, and published in Health Effects of Plutonium and Radium, W.S.S. Jee, Ed., The J.W. Press, Salt Lake City, Utah, pp. 421–436 (1976).

†Present address: Washington University School of Medicine, St. Louis, Mo.

MICROSCOPIC DISTRIBUTION OF ^{226}Ra IN THE BONES OF RADIUM CASES: A COMPARISON BETWEEN DIFFUSE AND AVERAGE ^{226}Ra CONCENTRATIONS*

R. A. Schlenker and J. E. Farnham

Diffuse concentration measurements were made with alpha track autoradiography at various sites in the skeletons of 10 radium cases. The ratio of the highest to the lowest concentration observed within a skeleton was found to be 2.8 ± 1.4. Measurements were made at five pairs of contralateral sites in one case, and bilateral asymmetry was found. Diffuse and average concentrations showed similar distribution patterns along the lengths of femora from three cases. Ratios of diffuse-to-uniform concentration, when analyzed using the ICRP model of alkaline earth metabolism, indicated that the most representative compact bone remodeling rate for these skeletons was in the range 0 to 0.4%/year.

*Abstract of a paper published in The Health Effects of Plutonium and Radium, W. S. S. Jee, Ed., J. W. Press, Salt Lake City, pp. 437–449 (1976).

MACRODISTRIBUTION OF PLUTONIUM IN SELECTED BONES FROM AN ABNORMAL SKELETON*

R. P. Larsen, R. E. Toohey, and F. H. Ilcewicz+

The burden and macrodistribution of plutonium in the skeletal remains of a woman who in 1945 received 0.3 μCi of plutonium by injection are being determined. At the time of injection she was suffering from Cushing's syndrome, hypertension, nephropathy with uremia, and osteoporosis; she succumbed to her illness in 1947 at age 19. The plutonium she received was tetravalent and in a citrate buffer medium. The subject, referred to in the early literature as HP-4,[1] has been assigned CHR case number 40-010. Preliminary results obtained by using both a xenon-filled proportional counter and radiochemical methods to determine plutonium in solutions of dissolved bone ash were reported previously.[2]

The results of the radiochemical determinations of plutonium (by alpha spectrometric-isotopic dilution) in several bone samples are reported in Table 1. The distribution of plutonium down the length of the right tibia has been determined. The bone was cut into ten sections of equal lengths, and each section was ashed, weighed, dissolved in nitric acid, and analyzed radiochemically. The results are given in Table 2, and Figure 1 shows the plutonium concentration as a function of distance from the proximal end.

As expected for a radionuclide that deposits on bone surfaces, the plutonium concentrations in bones that are primarily trabecular are significantly higher than those that are primarily cortical. The concentrations in the vertebra and the two portions of bone from the innominate are factors of 34, 26, and 22, respectively, higher than the concentration in the humerus midshaft. The difference between bones that are primarily trabecular and primarily cortical also exists within particular bones. The concentration in the humerus head is

---

*Summary of paper published in The Health Effects of Plutonium and Radium, W. S. S. Jee, Ed., The J. W. Press, Salt Lake City, pp. 315–320 (1976).

+Deceased.

Table 1. Concentration of plutonium in bone samples of case 40-010.

Bone	Plutonium Concentration (pCi/g ash)
First lumbar vertebra	844 ± 20
Femur head	141 ± 4
Humerus head	156 ± 5
Humerus midshaft	25 ± 0.4
Innominate	645 ± 20
Innominate	553 ± 13
7th rib	320 ± 3

Table 2. Concentration of plutonium in the right tibia of case 40-010.

Distance from proximal end (cm)	Ash weight (g)	Plutonium concentration (pCi/g ash)
0 — 3.5	9.73	58.4 ± 1.2
3.5— 7.0	5.86	32.9 ± 0.6
7.0—10.5	8.30	20.9 ± 0.4
10.5—14.0	7.77	14.3 ± 0.3
14.0—17.5	7.49	15.1 ± 0.4
17.5—21.0	6.85	12.2 ± 0.4
21.0—24.5	6.32	12.1 ± 0.3
24.5—28.0	4.73	17.8 ± 0.3
28.0—31.5	4.42	20.4 ± 0.6
31.5—35	4.88	34.4 ± 1.2

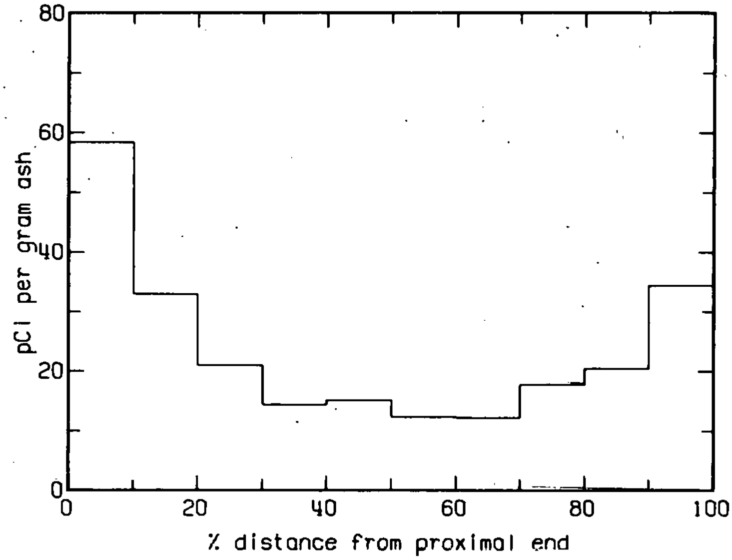

FIG. 1.--Distribution of plutonium in the right tibia of case 40-010.

a factor of six higher than that in the midshaft, and the concentration in the proximal end of the tibia is a factor of five higher than that in the midshaft.

From the data obtained to date, it appears that the best estimate of total skeletal burden may be obtained from the analysis of a rib. The burdens calculated from the values obtained for the first lumbar vertebra, the innominate, the head of femur, the entire tibia, and the seventh rib are 0.38, 0.56, 0.64, 0.027, and 0.084 μCi, respectively. The estimated burden is 0.14 μCi. This estimate was made from the amount of plutonium injected, less a small correction for the amount eliminated prior to death, and from the ICRP value of 0.45 for the fraction retained in the skeleton.

References

1. W. H. Langham, S. H. Bassett, P. S. Harris, and R. E. Carter, Distribution and Excretion of Plutonium Administered Intravenously to Man. Los Alamos Scientific Laboratory Report LASL-1151 (1950).
2. R. E. Toohey, R. P. Larsen, and F. H. Ilcewicz, A preliminary report on the macrodistribution of radioactivity in the skeleton of an individual who received plutonium by intravenous injection, Radiological and Environmental Research Division Annual Report, July 1974—June 1975, ANL-75-60, Part II, pp. 92—95.

MICROSCOPIC DISTRIBUTION OF ^{239}Pu DEPOSITED IN BONE FROM A HUMAN INJECTION CASE*

R. A. Schlenker, Billie G. Oltman, and Helen T. Cummins

The distribution of ^{239}Pu was studied in bone from a woman who received an intravenous injection of 0.3 μCi ^{239}Pu in 1945 at age 18 and who died 17 months later with Cushing's syndrome. The average depth at which ^{239}Pu was buried by appositional bone growth in trabeculae ranged from 40 to 60 μm in seven bones. The average for all sites of burial studied was 52 μm. Surface and volume concentrations in bone which covered buried surfaces in trabeculae ranged between 0.26 and 0.63 pCi/cm^2 and 56 to 160 pCi/cm^3, respectively, in seven bones. The mean values of the data for the seven bones were 0.39 pCi/cm^2 and 94 pCi/cm^3. The volume concentration contributes only about 4% of the total terminal dose rate in a layer of cells 10 μm thick lining the endosteal surfaces of trabeculae in the 6th thoracic vertebra. In other bones the contribution from bone volume would be even less. Concentrations on the periosteal, endosteal, and Haversian canal surfaces in the shafts of six long bones ranged between 0.18 and 0.64 pCi/cm^2, 0.14 and 0.31 pCi/cm^2, and 0.13 and 0.59 pCi/cm^2, respectively. These concentrations are considerably less than those observed on buried surfaces at the same sites.

---

*Abstract of a paper published in The Health Effects of Plutonium and Radium, W. S. S. Jee, Ed., J. W. Press, Salt Lake City, pp. 321–328 (1976).

COMPARISON OF THE LATE EXCRETION OF ^{226}Ra AND ^{239}Pu BY MAN*

J. Rundo and R. B. Holtzman

Excretion rates of radium (12 cases) and plutonium (2 cases) at roughly 10^3 and 10^4 days after intake are reviewed and compared with each other and with the predictions of various models. There are some superficial similarities between the excretory patterns of the two elements, but there are more differences. At 1000 to 2000 days after intake the fraction of the initial dose excreted daily is of the order of 10^{-3}% for either element; at 10^4 days it is much lower for radium (order of 10^{-5}%) but unchanged or higher for plutonium.

On the other hand, the coefficients of elimination (fraction of contemporary body content excreted daily) for the two elements differ by almost two orders of magnitude at 10^3 days, but are rather similar at 10^4 days at about 4×10^{-3}% per day. This implies an instantaneous biological half-life of about 46 years. The ICRP power function-type model for radium[1] provides a reasonable fit to the data at both 10^3 and 10^4 days, whereas the ICRP exponential model for plutonium[2] agrees with the data at 10^4 days, but overestimates the coefficient of elimination at 10^3 days by a factor of about two. Among the 11 subjects for whom there were data on radium at 10^4 days, there was an order of magnitude difference between the highest and lowest coefficients of elimination. There was no evidence that this was due to a radiation effect.

References

1. International Commission on Radiological Protection (ICRP), Publication 20, Alkaline Earth Metabolism in Adult Man (1972).
2. International Commission on Radiological Protection (ICRP), Publication 19, The Metabolism of Compounds of Plutonium and Other Actinides (1972).

---

*Summary of a paper published in The Health Effects of Plutonium and Radium, W.S.S. Jee, Ed., The J. W. Press, Salt Lake City, pp. 497–504 (1976).

VARIABILITY IN THE EXHALATION RATE OF RADON

J. Rundo, F. Markun, J. Y. Sha, and P. Cameron*

In a day-long study, twenty-eight 10-min samples of breath were collected from a former radium dial painter and were analyzed for radon. The radon exhalation rate showed good short-term reproducibility, but there was a dramatic short-lived increase in the first samples collected after lunch and a slow but steady increase during the course of the day.

Previous reports from this laboratory have described a series of experiments designed to study reproducibility of measurements of radioactivity in vivo.[1] During the course of a week the exhalation rate of radon by two former radium dial painters showed remarkable variability, particularly from morning to afternoon. In order to get more information on this variability, which we had noticed on isolated occasions with one or two other patients, we made a day-long study of the exhalation rate of radon by case 03-685, who had participated in the previous week-long series. The subject, a 74-year old woman had worked as a radium dial painter for a total of about 15 months starting in 1921. Her estimated content of ^{226}Ra was approximately 84 nCi in 1974. She entered the underground vault at 8:20 a.m. and remained there until 5:00 p.m., except for three periods of 4 to 5 min each when she visited the toilet. Following the gamma-ray measurements in the tilted chair, she sat in the reclining chair at 9:02 a.m. and collection of the first breath sample was started 10 min later. A total of twenty-eight 10-min collections was made. In the previous studies there appeared to have been a correlation between the exhalation rate of radon and the pulse. We therefore monitored the pulse continuously and automatically with a commercial pulse meter†, modified in the Electronics Division to permit scaling of the pulses and displaying the total at 1-min intervals.

---

*Consultant.
†San-Ie Pulsemeter, distributed by Medical Systems, Corp., Great Neck, N.Y.

The results are set out in Table 1, and they are presented graphically in Figure 1, where points representing the results of consecutive measurements (intervals without collection were 5 min or less) are joined by straight lines. The three visits to the toilet are indicated by arrows labelled U, and a 20-min period when the subject was eating her lunch (still in the vault) is also identified. Several facts emerge, of varying degrees of strikingness, and these will be discussed in order:

(a) there was a dramatic but short-lived increase in the exhalation rate of radon following lunch,

(b) there was a steady increase in the exhalation rate of radon during the day,

(c) the changes in posture associated with the first and third visits to the toilet had no noticeable effect on the exhalation rate of radon, the respiratory minute volume (RMV) or the pulse rate, and,

(d) there was good short-term reproducibility in the measurements of the exhalation rate of radon, although the observed variations were greater than the statistical errors of counting, which were in the range 1.2 to 1.6%.

The doubling of the exhalation rate of radon seen in the first sample collected after lunch confirms what was noted on several occasions in the week-long study.[1] The rapid decline of the exhalation rate to "normal values" offers a possible reason why the doubling was not seen every day. The timing could have been important.

The reason for this large but short-lived increase in the exhalation rate is not known, but two possibilities may be considered. First, this might have been exhalation of radon ingested in the lunch or (especially) drinking water. However, the subject drank no water with or after lunch and the boiling of water to make coffee, which she did have, would have driven off any dissolved radon. Ingestion of radon can probably be ruled out as the source. The alternative possibility is that the excess came from a "reservoir" of radon dissolved in the tissues of the abdomen, which was flushed out by the increased blood

TABLE 1. Results of day-long study of exhalation of radon.

Time of Day	Average pulse min^{-1}	RMV $l\ min^{-1}$	Exhalation rate of radon, $pCi\ min^{-1}$
0912—0922	76.4	6.40	4.81 ± 0.06
0924—0934	72.7	6.25	4.62
0936—0946	71.2	6.20	4.61
0948—0958	70.6	6.29	5.01
1000—1010	69.9	6.11	5.13
1014—1024	69.9	6.15	5.21
1029—1039	69.3	6.12	5.30
1044—1054	68.8	6.49	5.71 ± 0.07
1058—1108	69.6	6.02	5.23
1112—1122	70.5	5.89	5.85
1124—1128	Subject out of vault		
1134—1144	70.4	6.26	5.61
1147—1157	70.4	5.79	5.41
1205—1225	Subject eating lunch		
1255—1300	Subject out of vault		
1311—1321	77.2	6.31	11.43 ± 0.14
1323—1333	75.1	6.98	11.19
1335—1345	73.8	6.84	9.58
1348—1358	70.6	7.35	8.64
1400—1410	68.9	7.27	7.13
1414—1424	69.9	7.19	6.41
1427—1437	69.8	7.45	6.46
1440—1450	72.3	7.76	6.82 ± 0.11
1455—1459	Subject out of vault		
1512—1522	71.7	7.03	6.44
1524—1534	70.9	7.00	6.44
1536—1546	71.0	7.12	6.76
1551—1601	71.5	6.88	6.63
1603—1613	71.7	6.84	6.93
1615—1625	71.4	6.77	6.35
1627—1637	71.5	6.96	7.05
1639—1649	73.3	6.81	6.66 ± 0.09

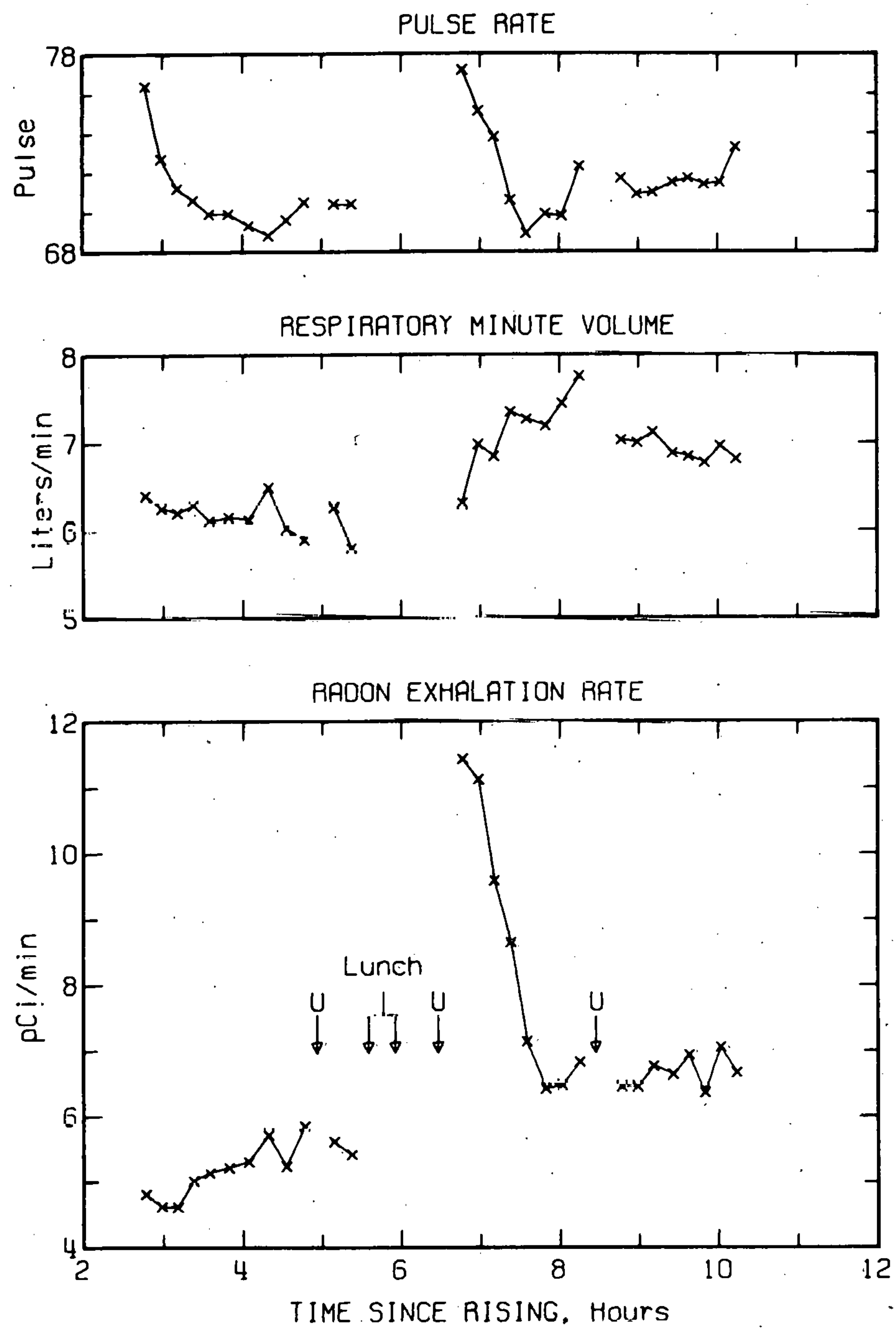

FIG. 1.--Pulse rate, respiratory minute volume and radon exhalation rate plotted against time since rising (6:30 a.m.). The subject left the underground vault briefly on three occasions, identified by the arrows marked U. Note the decline in pulse rate in the first 40 min, as the subject relaxed.

flow in the abdominal region, associated with the digestive process. It may be noteworthy that there is a strong correlation between the pulse rate and the radon exhalation rate for the first five samples taken after lunch ($r = 0.97$, $p < 0.01$); the correlation for the other samples, with the exclusion of the first hour, is also highly significant ($r = 0.72$, $p < 0.01$). The decrease in the pulse rate between 9:12 and 9:58 was probably a consequence of the subject relaxing after the start of the breath collections. There was no corresponding change in the exhalation rate of radon or the RMV in this time period.

There is also a negative correlation between the radon exhalation rates for the first five samples collected after lunch and the corresponding values of the RMV ($r = -0.77$), but a positive correlation for all the other samples ($r = +0.78$), with the results for the fifth sample after lunch belonging to both populations. The significance of these correlations is not fully understood, but it does seem likely that the short-lived increase in radon exhalation rate was associated with the digestive process.

No such explanation exists for the slow but steady increase in the rate of exhalation of radon during the whole experimental period from 9:15 a.m. to 4:50 p.m. A straight line can be drawn through the data (with the exclusion of the first five points after lunch), and a correlation coefficient of +0.95 was derived. However, such a fit is prophetically blind because the rate of exhalation of radon presumably decreased sometime after 5 p.m. The simplest cyclic function is a sinusoidal one, and when such a function was tried, the fit was apparently better than for the straight line, but the period was 34 ± 5 hr, somewhat longer than the expected value of 24 hr. The mean value of the rate of exhalation of radon for the cycle was 4.3 ± 0.1 pCi/1. There is, of course, no a posteriori reason to suppose that the variations were truly sinusoidal.

It might be argued that the constraints on movement and posture of the subject in the day-long confinement to the recliner created an unnatural situation which caused the slow change in the rate of exhalation of radon. However, when the results for 82 subjects were normalized and plotted as a function of time of day, there was a significant correlation, despite considerable scatter

($r = +0.30$, $p \approx 0.01$). The regression equation predicted that the rate of exhalation of radon would be 44% higher at 5:00 p.m. than at 9:00 a.m. From the data in Table 1, the mean rate of exhalation of radon for the last three observations centered at 4:32 p.m. was 43% higher than the mean for the first three observations at 9:29 a.m. (6.69 pCi/min, compared with 4.68 pCi/min). The 82 subjects were not constrained in a single near-supine position during the day, so the increase observed for case 03-685 does seem to be real, even if unexplained.

An estimate of the "excess" radon exhaled in the period following lunch may be made with the use of one or other of the regression lines (linear or sinusoidal). Using the linear fit, we obtained the results in Table 2. To calculate the total, each excess value was multiplied by 10 (minutes) and allowance was made for the four intervals of 2 or 3 min each between samples when breath was not collected. The total excess radon exhaled between 1311 and 1410 was then 210 pCi. Unfortunately, we have no data for the 46-min period between the end of lunch and the first sample after lunch. It would have been interesting to know how soon after lunch the exhalation rate started to increase and how rapidly.

TABLE 2. Excess over "expected" (linear fit) of exhalation rate of radon after lunch.

Time of Collection	Exhalation Rate of Radon, pCi/min		
	Observed	"Expected"	Excess
1311—1321	11.43	5.93	5.50
1323—1333	11.19	5.98	5.21
1335—1345	9.58	6.04	3.53
1348—1358	8.64	6.09	2.55
1400—1410	7.13	6.15	0.98

The change of posture and small amount of exercise involved in the visit to the toilet at 12:55 can have played no part in the increase in the exhalation rate of radon after lunch, in view of the lack of effect of the two similar visits at 11:25 and 14:55. This is of particular interest in view of the known effects of posture on the exhalation rate of radon.[2]

Finally, it is evident from Figure 1 that the short-term variability of the exhalation rate of radon is quite small, although greater than the statistical errors of counting. A quantitative estimate of the coefficient of variation was possible by normalization of the observed values with values predicted by the sinusoidal fit (with the exclusion of the first five values after lunch). The standard deviation of the normalized data was 3.6% of the mean value. Elimination of the average statistical error of 1.28% left 3.4% as the nonstatistical error due to all other sources (sampling of breath, transfer of radon and biological variability). This number is gratifyingly small.

In conclusion, the results of the day-long study reported here have shed new light on the variability of the rate of exhalation of radon from persons with long-standing burdens of radium. It is still not clear when the most representative value can be obtained, but it is obvious that breath should not be sampled shortly after a meal.

Acknowledgements

The authors gratefully acknowledge the whole-hearted cooperation of the subject of these experiments. D. R. Huff and M. A. Essling gave important technical assistance during the day.

References

1. D. R. Huff, F. Markun, and M. A. Essling, Studies of the reproducibility of measurements of radioactivity in vivo, Radiological and Environmental Research Division Annual Report, July 1974—June 1975, ANL-75-60, Part II, pp. 120—127.
2. E. J. Martin and J. K. W. Ferguson, Effect of posture on the elimination of radon in the breath, Science 118, 112—114 (1953).

AN UNUSUAL CASE OF INTERNAL CONTAMINATION WITH ^{241}Am

J. Rundo, M. Essling, D. R. Huff, and W. D. Fairman*

A woman accidentally swallowed two sources of ^{241}Am of the type used in domestic smoke detectors; the nominal activity of each source was 2.5 μCi, and they were not voided until the 16th and 24th days after intake. A little less than 1% of the total activity of the two sources was found in the fecal material after removal of the sources and ^{241}Am was detected in the urine until the second source had been voided.

Introduction

A female employee of a local electronics firm engaged in the manufacture of domestic smoke detectors containing ^{241}Am, was referred to us by the Nuclear Regulatory Commission's Compliance Division for investigation of possible radioactive content. She was thought to have swallowed a source of ^{241}Am (nominal activity 2.5 μCi), deposited on a silver disk 2.35 mm in diameter and 0.2 mm thick, and coated with a very thin layer of gold. Radiographs of the abdominal region 11 days after the putative intake had failed to reveal the presence of such a radiopaque object, and it was thought that it had been voided in the feces. Our help was requested in order to confirm this belief. Urine and feces collected at a local hospital on day 11 were sent to ANL for assay of ^{241}Am by the Bioassay Group of OHS Division, ANL.

Body Radioactivity Measurements

The subject (CHR case number 30-063) came for body radioactivity measurement on day 14. A measurement in the tilted chair revealed the presence of a substantial amount of ^{241}Am. An attempt was made to localize this from a longitudinal profile scan taken with a 1-cm wide slit-collimated detector. Because the subject complained of having had a sensation of "something stuck in the throat," the scan covered the interval 15 to 80 cm from the vertex. Her height was 156 cm. The profile curve, shown in Figure 1, revealed no

---

*Occupational Health and Safety Division, ANL.

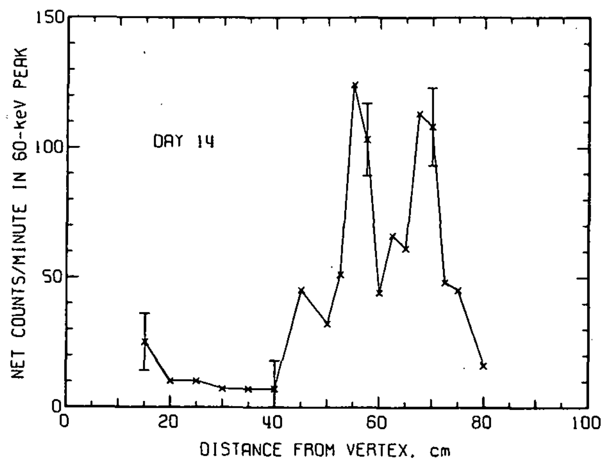

FIG. 1.--Radioactive profile curve (slit-collimated 29-cm diameter detector), showing the presence of two sources in the abdomen (case 30-063).

significant excess activity in the pharyngeal region, but two sharp peaks, centered at about 56 cm and 68 cm from the vertex, demonstrated the presence of <u>two</u> sources in the abdomen.

Measurements were also made in arc geometry, to establish the total content. The interpretation of the counting data posed an unusual problem because of the attenuation of the 60-keV gamma rays in the silver foil, and of the impossibility of knowing the direction(s) that the sources were facing. Thus, with a mass attenuation coefficient of 5.49 $cm^2\ g^{-1}$ for 60-keV gamma rays in silver of density 10.5 g cm^{-3}, the intensity of the photons from the gold-coated side (attenuation ignored) should be 3.16 times the intensity from the other side (silver thickness 0.02 cm). The observed ratio of the counting rates from front and back of the subject in the 1.5-m arc was 3.7 ± 0.1; this suggested that both sources were facing in the same direction, i.e., gold-coated side forward, since the higher counting rate was observed from the front of the subject. However, it is entirely possible for a ratio of 3.7 to be observed from a source of ^{241}Am in vivo if it is about 6 cm deep in a 20.4-cm thick abdomen, and is <u>not</u> backed by severely attenuating material. In the absence of other information, we assumed that the sources were both close to the midplane of the abdomen. In making the calculation of the content, R, we used the following equation:

$$R = \sqrt{3.16\ N_1 N_2} \times \left(\frac{D-d}{D}\right)^2 \times e^{\mu d} \times f_{fs} \times \frac{S}{N_3}\ \mu\text{Ci} \quad , \qquad (1)$$

where 3.16 is the calculated counting-rate ratio for the disk sources,

N_1 is the counting-rate (min^{-1}) from the front of the subject,

N_2 is the counting-rate (min^{-1}) from the back of the subject,

D is the radius of the arc (150 cm),

d is the half-thickness of the abdomen (10.2 cm),

μ is the measured linear attenuation coefficient of 60-keV γ rays in tissue-equivalent material ($0.15\ cm^{-1}$),

f_{fs} is a forward scatter correction (0.763),

S is the activity of the standard source, and

N_3 is the counting-rate (min^{-1}) from the standard source counted at 150 cm.

We observed values of 750 ± 9 and 203 ± 5 counts/min for N_1 and N_2 respectively, S was 9.8 μCi and N_3 was 4472 counts/min. Inserting these and the other values in Eq. 1, we obtain

$$R = 4.65\ \mu Ci\ .$$

The factor of 3.16 enters the equation for R to correct the counting rate for attenuation in the silver. The value of 4.65 μCi for R is in reasonable agreement with the expected value of 5.0 μCi for two sources.

On day 16, a fecal sample was voided and when examined by gamma-ray spectrometry, it was found to contain a substantial amount of ^{241}Am. We shall discuss the examination of this and of a subsequent sample below.

A second determination of body radioactivity was made on day 21. ^{241}Am was still present and measurements were again made in arc geometry; time did not permit localization measurements. As on day 14, the counting rate from the front ($432 \pm 7\ min^{-1}$) was much greater than that from the back ($138 \pm 4\ min^{-1}$); the ratio was 3.1 ± 0.1. From Eq. 1, we obtain

$$R - 2.72\ \mu Ci\ .$$

This second source was found in feces voided on day 24, no other samples having been voided in the interim, and a third examination of body radioactivity on day 28 revealed no detectable content of ^{241}Am.

The two fecal samples were radiographed for us by the Non-Destructive Testing Group of the Quality Assurance Division (ANL), and each was seen to

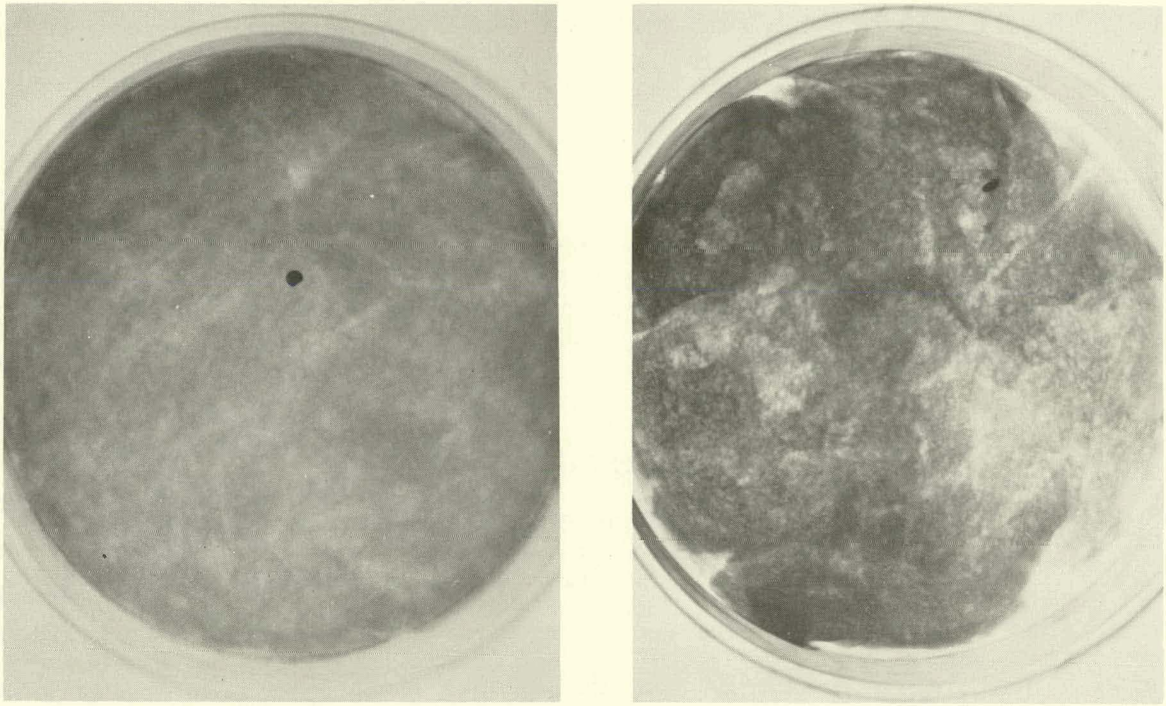

FIG. 2.--Prints made from radiographs of fecal samples (in plastic bags inside waxed cardboard cartons) voided 16 days (left) and 24 days after the incident. The silver disks are easily seen. (ANL neg. 235-76-21)

contain a small disk of a dense material. Prints from the radiographs are shown in Figure 2. In the sample voided on day 16, the disk is seen almost in plan view, and it presents as an incomplete circle with a short straight edge. The shadow of the disk in the sample voided on day 24 is seen as an eccentric ellipse. Each disk was isolated from the feces, washed in a little water, dried and mounted in a cardboard slide mount between two sheets of laminator film* 0.04 mm thick. The activities of the two sources were estimated to be 1.86 ± 0.02 μCi (day 16) and 2.36 ± 0.02 μCi (day 24). The water used to wash the sources contained no detectable activity (limit 100 pCi).

Apparently Eq. 1 gave overestimates of the contents of the subject on both occasions, and the principal reason for this is the use of the calculated ratio, 3.16, of the counting rates from the two sides of the sources. After isolation from the feces, this ratio was determined to be 2.1, indicating that the silver foil may have been thinner than 0.2 mm, or that the mass attenuation coefficient was smaller than 5.49 $cm^2\ g^{-1}$, or both. In retrospect, we can

---

*Ply-On, available from American Photocopy Co., Evanston, Ill.

correct the estimates of body content by the ratio $\sqrt{2.1/3.16} = 0.815$, obtaining 3.8 μCi and 2.2 μCi for days 14 and 21, respectively. These are in slightly better agreement with the known activities of the two sources, and the validity of Eq. 1 is established.

Excretion Analysis

Following the subject's visit to ANL on day 14, she was asked to collect and submit all urine and feces voided. Most urine voided between days 14 and 31 was received and analyzed for ^{241}Am, as was the 550-ml sample collected in hospital on day 11. Samples voided from day 23 onward contained no detectable ^{241}Am (limit 0.1 pCi); the results for the other samples are set out in Table 1. Not all samples represented 24-hr excretions. The subject voided feces rather infrequently (usually about once a week). Samples were voided on days 11 (in hospital), 16, and 24. At this time, she was treated with cathartics which caused diarrhea for several days, and she did not collect these samples. Two other fecal samples voided on days 30 and 31 were received. The results of the analyses for ^{241}Am are set out in Table 2. The samples voided on days 16 and 24 were the ones which contained the active disks, and the amounts of activity reported in Table 2 were found in the feces after removal of the disks. The total activity recovered in feces, 34.7 nCi, amounted to about 0.8% of the activity on the two disks (4.22 μCi). A little more may have been voided during the period of diarrhea.

The presence of detectable ^{241}Am in the urine until day 23 proved that there was some entry into blood, but the fall below the limit of detection on day 24 showed that the systemic content must have been very small. A very approximate upper limit for the intake to the blood can be calculated if we make the pessimistic assumptions that the activity entered the blood on day 1, that the urinary excretion rate on day 24 was equal to the limit of detection (0.1 pCi/day), and that the excretion rate followed Langham's power function equation for plutonium. With these assumptions, a value of 525 pCi is calculated, and this must be an extreme upper limit. It is negligible from the point of view of radiological protection. It is obvious from the results in

Table 1. Urine samples and their contents of ^{241}Am

Days since intake	Collection period, hr	^{241}Am content of sample, pCi ± 2σ
11	?	0.18 ± 0.04
14—15	13	0.22 ± 0.05
15—16	24	0.22 ± 0.04
16—17	24	1.3 ± 0.2
17—18	24	0.31 ± 0.06
20—21	19	<0.1
21—22	21.5	0.35 ± 0.06
22—23	24	0.23 ± 0.04

Table 2. Contents of ^{241}Am in five fecal samples

Days since intake	^{241}Am content of sample, pCi ± 2σ
11	194 ± 32
16	17,700 ± 2900
24	16,800 ± 2800
30	≤1.8
31	≤0.9

Table 1 that the urinary excretion of ^{241}Am was being supported by the continued presence of the second source in the gastrointestinal tract, and it fell below the limit of detection in the 24-hr sample excreted just before the source was voided in the feces. The actual initial systemic burden must therefore have been much lower than 525 pCi.

Finally, it may be noted that a little more ^{241}Am was lost from the body than was accounted for in the feces, because about 2 nCi were found in the trousers of the pajamas worn by the subject when the body radioactivity was investigated on day 14. This was attributed to contamination from the anal region, and other clothing worn between days 11 and 24 may have been similarly contaminated.

Conclusions

A most unusual feature of this case was the long delay between intake and voiding of the sources. They were not in the abdomen on day 11 (radiographic evidence) but they were there three days later (Figure 1). It was suggested by a consulting physician that they may have been trapped in the vallecula or the pyriform sinus, or elsewhere in the pharynx. This would account for the holdup and for the reported discomfort in the throat. We can only speculate on whether the sources left the pharyngeal region together or separately. In any event, it seems that the first source was voided in the feces with little delay after entry into the stomach.

If the sources of ^{241}Am involved in this incident are representative of those incorporated in the domestic smoke detectors, then the most important conclusion that can be drawn is that they are remarkably secure. Apparently they lose very little (less than 1% in the present case) of their radioactive content when exposed to body fluids (although not necessarily gastric juices all the time) for 16 days or more. Furthermore, what activity is released under these circumstances is so inert that there is negligible absorption into the blood. This is an important and comforting finding in view of the growing numbers of smoke detectors available to the general public.

Another important conclusion, but in a different context, is the validation of Eq. 1 for the calculation of the body content. A slightly different version of the equation is used to calculate the body content of radium daughters, and this was the first opportunity we have had to determine directly the validity of this approach.

Acknowledgements

We thank Robert L. Irwin and Joseph W. Lucas of the Quality Assurance Division for making the radiographs of the fecal samples. Fred S. Iwami,

Theresa L. McFall, and Jean J. Robinson of the Occupational Health and Safety Division made the measurements of ^{241}Am in the excreta.

MARROW, OVARY, AND BREAST DOSES DELIVERED BY CHR DIAGNOSTIC X-RAY PROCEDURES

R. A. Schlenker and B. G. Oltman

Doses to the active marrow, ovaries, and breasts delivered by the diagnostic x-ray procedures used in the Center for Human Radiobiology are being estimated by measurements in a female RANDO phantom. Measurements are made at the sites of the target tissues by inserting LiF thermoluminescent dosimeters into holes drilled in the marrow spaces, at the positions of the ovaries and in the breasts. The dose to the active marrow is 169 ± 17 mrad with 1 mm Al added filtration and 177 ± 17 mrad with 3 mm Al added filtration. The ovary dose is 197 ± 26 mrad and 168 ± 12 mrad for 1 and 3 mm Al, respectively. Breast dose is currently being measured.*

Introduction

The medical examination given to patients studied at the Center for Human Radiobiology includes a complete diagnostic x-ray survey of the skeleton, sinuses, and mastoids. Estimates were made previously of the doses delivered to the active marrow and ovaries.[1–3] These estimates employed radiation exposure data reported by others. In order to improve our estimates we are measuring the dose in an anthropomorphic phantom subjected to the same type of x-ray examination that a patient receives. We report here the progress we have made in these measurements.

In order to make realistic measurements we insert thermoluminescent dosimeters into holes which have been drilled within the marrow spaces, at the positions of the ovaries and in the breasts in a female RANDO phantom.† Dose measurements are made at 91 positions scattered throughout the volume of active marrow, at 32 positions spread throughout the volume thought to be occupied by the ovaries, and at 40 positions spread throughout the breasts. The measurement of breast dose is still in progress and the accuracy of the dosimeter calibration is being checked.

---

*A preliminary estimate indicates that the breast dose is within a factor of two of 75 mrad.

†Alderson Research Laboratories, Stamford, Connecticut, Product No. RAN-110.

The Phantom

The phantom has the shape of a lean, well-proportioned female 163 cm tall and 54 kg in weight, but it lacks arms, and its legs end at mid-thigh. It contains a skeleton embedded in a "tissue equivalent" medium having a density of 0.985 g/cm^3 and an effective atomic number of 7.30.[4] The lung material has the same composition but has been impregnated with air to lower its density to 0.3 g/cm^3. The lungs are expanded to a neutral respiratory volume, and the left lung is smaller than the right lung to allow for the heart. The pharynges, larynx, trachea, and stem bronchi are air filled. Breasts of various sizes may be attached to the chest; those used in our study were size C.* The external dimensions of the skeleton are small compared with the dimensions of the phantom, indicating that the donor was shorter and thinner than the female form on which the phantom is based. The phantom is sliced transversely into 35 sections to allow access to the body interior. The sections are 2.5 cm thick with the exception of the end sections, which are somewhat thicker.

X-Ray Examination

The patient and phantom examinations are made with a General Electric model DXD-350 x-ray machine. It has a single phase full wave recitified power supply; the focal spot is 2.3 mm and the tube and collimator together have an inherent filtration of 2.5 mm Al. One millimeter Al additional filtration is used in all patient examinations at present although 3 mm Al have been used in the past. Phantom exposures were made with both 1 mm and 3 mm added filtration so that the effect of different filtrations could be determined.

The patient examination consists of 35 projections made with a focus-to-film distance of 40 in. These are listed in Table 1 with the kVp and mAs for each. Since the phantom has no arms and has only leg stumps, it received only 23 exposures as indicated in the table.

A Potter-Bucky grid is used with each of the phototimed exposures to reduce scattered radiation. Also, a high speed screen and high speed film

---

*Alderson Research Laboratories, Stamford, Connecticut, Product No. RAN-140-C-W.

TABLE 1. X-ray Examination Given to Patients and Phantom

Projection	kVp	mAs*	Phantom
Skull, AP	80	pt	yes
Skull, lat.	80	pt	yes
Skull, mod. Waters, PA	80	pt	yes
Sphenoid, PA	80	pt	yes
Law's view of mastoids, r. & l., lat.	80	pt	yes
Stenvers' view of mastoids, r. & l., tang.	80	pt	yes
Mandible, r. & l., tang.	80	pt	yes
Cervical spine, AP	70	pt	yes
Cervical spine, lat.	78	30	yes
Chest, PA	104	pt	yes
Chest, lat.	104	pt	yes
Thoracic spine, AP	76	pt	yes
Thoracic spine, lat.	78	pt	yes
Lumbar spine, AP	72	pt	yes
Lumbar spine, lat.	78	pt	yes
Pelvis, AP	72	pt	yes
Shoulder, r. & l., AP	48	pt	yes
Femur, r. & l., AP	58	pt	yes
Lower arm, r. & l., AP	48	pt	no
Wrist and hand, r. & l., AP	40	pt	no
Lower leg, r. & l., AP	50	pt	no
Ankle, r. & l., AP	52	15	no
Foot, r. & l., AP	46	15	no
Foot, r. & l., lat.	44	15	no

* The entry "pt indicates that the mAs was controlled by the phototimer. The mAs will vary according to the position of the patient relative to the phototimer and according to the patient thickness.

are used with automatic processing.*

Marrow and Ovary Dose Measurement

Extruded rods of LiF measuring 1 × 1 × 6 mm† are enclosed within heat shrinkable plastic tubing and inserted into the marrow space and ovary holes. The phantom is assembled and positioned on the x-ray table exactly as a patient would be. The head is detached from the torso for exposure so that the proper angles can be maintained between the head and the x-ray beam. Each projection is repeated 5 times in rapid succession to insure that the luminescence from the LiF rods will greatly exceed instrumental background.

Before use, the dosimeters are annealed for 1 hr at 400 C and then for 24 hr at 85 C. After exposure at least 24 hr are allowed to pass before reading. The reader was built in our laboratories.

The response per rad of absorbed dose in LiF powder is the same for x rays generated at 20 to 50 kVp as it is for ^{60}Co gamma rays.[5] This suggests that the response is independent of x-ray energy throughout the diagnostic range. If so, then

$$L = k\,D_{LiF} \tag{1}$$

where L is the response, D_{LiF} is the absorbed dose, and k is a proportionality factor which is independent of energy.

When the expression[6] for absorbed dose in terms of exposure, X, is substituted into this equation, the result is a relationship between exposure and response which can be written as follows:

$$\frac{X}{L} = \frac{1}{0.869k}\;\frac{(\bar{\mu}_{en}/\rho)air}{(\bar{\mu}_{en}/\rho)LiF}\quad , \tag{2}$$

where $(\bar{\mu}_{en}/\rho)$ is the mean mass energy absorption coefficient for the x-ray beam. The right-hand side of the equation was evaluated empirically over the

---

*Eastman Kodak Co., Rochester, New York, X-Omatic Regular Intensifying Screen, X-Omat R film XR-5, RP X-Omat Processor.

†Harshaw Chemical Co., Cleveland, Ohio, LiF, TLD-100, high sensitivity rods.

range of kVp used in the x-ray examination. To do this, the beam exposure was measured with a calibrated ionization chamber.* LiF dosimeters were then placed at the position of the ionization chamber, and a second exposure was made with the same control panel settings. Between 50 and 124 kVp the value of X/L was constant with a value of 3.46 ± 0.13 mR per unit of response when 1 mm added filtration was used. The equation which relates exposure to response is thus

$$X = 3.46\,L\,. \tag{3}$$

With the exposure known the absorbed dose in the marrow and ovaries can be computed if one assumes that the energy absorption coefficient of gonadal and marrow tissue is equal to that for muscle. Thus, when 3.46 L is substituted for X in the standard equation for absorbed dose in terms of exposure,[6] the result obtained is

$$D_{\text{marrow or ovary}} = 0.869\ \frac{(\bar{\mu}_{en}/\rho)\ \text{muscle}}{(\bar{\mu}_{en}/\rho)\ \text{air}}\ (3.46\,L)\,. \tag{4}$$

The quantity $0.869\ (\bar{\mu}_{en}/\rho)\ \text{muscle}/(\bar{\mu}_{en}/\rho)\ \text{air}$ varies between 0.914 and 0.956 for monoenergetic x rays with energies in the range 15 to 150 keV.[7] This range includes all the photon energies encountered in the diagnostic x-ray examination. If the mid-range value of 0.935 is used in the equation, then the maximum systematic error in the dose introduced by using a constant value for this quantity is only 2.2%. Thus, dosimeter response is converted to dose by the following equation:

$$D_{\text{marrow or ovary}} = 3.24\,L\,. \tag{5}$$

Marrow Dose

The mean dose to the active marrow was computed by taking a weighted average of the doses to skeletal regions with known active marrow content.

---

*Victoreen Instrument Co., Cleveland, Ohio, Model 555, Radocon II, integrating ratemeter with 0.1 DAS ionization chamber.

Thus,

$$\bar{D}_{marrow} = \frac{\sum_i (D_{marrow})_i \, (W_{marrow})_i}{\sum_i (W_{marrow})_i} \,, \qquad (6)$$

where $(D_{marrow})_i$ is the dose to the ith region and $(W_{marrow})_i$ is the weight of active marrow in the ith region. Active marrow was assumed to be distributed in the manner described by Ellis.[8]

The measurement was repeated 3 times for both 1 mm and 3 mm added filtration in order to estimate the measurement precision. Results are presented in Tables 2 and 3. There the integral absorbed doses are given for 3 subregions of the phantom: the head and neck, the chest, and the abdomen and pelvis. The integral dose values were computed on the assumption of 1000 g active marrow. The totals and averages can thus be read either in units of g rad or in units of mrad.

Ovary Dose

The mean dose to the ovaries was computed by averaging the doses accumulated by each dosimeter. The measurements was repeated 3 times for both 1 mm and 3 mm added filtration with the following results:

1 mm: 197 ± 26 mrad

3 mm: 168 ± 12 mrad .

Discussion

The marrow integral dose to the abdomen and pelvis region is about 3 times the integral dose to the head and neck region or to the chest region. This occurs because the abdomen and pelvis region contains approximately twice as much active marrow as either of the other regions. In addition, the abdomen and pelvis region, because of its greater thickness, produces greater attenuation of the x-ray beam, and thus requires more radiation exposure to produce a radiograph of acceptable optical density.

The 1-mm and 3-mm beams produce average doses which are not significantly different from one another either in the marrow spaces or the

TABLE 2. Marrow integral dose with 1 mm Al added filtration based on 1000 g active marrow

Anatomical region	Dose, g rad* A	B	C	Avg. ± S.D.
Head and neck	27	27	35	30 ± 5
Chest	30	32	36	33 ± 3
Abdomen and pelvis	104	98	118	107 ± 10
Totals	161	157	189	169 ± 18

* Three replications were made; data for each are given in the columns A, B, and C.

TABLE 3. Marrow integral dose with 3 mm Al added filtration based on 1000 g active marrow

Anatomical region	Dose, g rad* A	B	C	Avg. ± S.D.
Head and neck	35	45	31	37 ± 7
Chest	39	49	35	41 ± 7
Abdomen and pelvis	96	102	98	99 ± 3
Totals	170	196	164	177 ± 17

* Three replications were made; data for each are given in the colums A, B, and C.

ovaries. Thus, while one would anticipate that the 1-mm beam would produce a higher absorbed dose than the 3-mm beam because of its lower effective energy, the variance in the measurements masks any such difference.

References

1. L. D. Marinelli, An estimate of the average absorbed dose to bone marrow of patients subjected to complete skeletal x-ray diagnostic procedures at Argonne National Laboratory, Radiological and Environmental Research Division Annual Report, July 1970—June 1971, ANL-7860, Part II, pp. 51—58.
2. Robert A. Schlenker and Billie G. Oltman, Bone marrow dose from x-ray examination of the skeleton, Radiological and Environmental Research Division Annual Report, July 1972—June 1973, ANL-8060, Part II, pp. 115—145.
3. Robert A. Schlenker, Gonadal dose from x-ray examination of the skeleton, Radiological and Environmental Research Division Annual Report, July 1972—June 1973, ANL-8060, Part II, pp. 146—156.
4. Samuel W. Alderson, Lawrence H. Lanzl, Marvin Rollins, and Jack Spira, An instrumented phantom system for analog computation of treatment plans, Am. J. Roentgenol. 87, 185—195 (1962).
5. J. Law, The dosimetry of low energy x rays using LiF, Phys. Med. Biol. 18, 38—45 (1973).
6. National Bureau of Standards Handbook 85, Physical Aspects of Irradiation, Nat. Bur. Stds., Washington, D.C. (1964).
7. ICRU Report 17, Radiation dosimetry: x rays generated at potentials of 5 to 150 kV, International Commission on Radiation Units and Measurements, Washington, D.C., p. 28 (1970).
8. R. E. Ellis, The distribution of active bone marrow in the adult, Phys. Med. Biol. 5, 255—258 (1961).

THE MACRODISTRIBUTION OF ^{226}Ra IN THE HUMAN SKELETON AS DETERMINED IN VITRO BY GAMMA-RAY SPECTROMETRY

M. A. Essling and D. R. Huff

A large number of γ-ray measurements of ^{226}Ra in human bone has been made both at MIT and CHR-ANL. These data are analyzed for correlations of the specific activity ratio of a bone group with other parameters, an interlaboratory comparison of the measurements, and an estimate of the errors expected when a whole-body content is calculated from the ^{226}Ra determination on a partial skeleton.

In a project begun at the Massachusetts Institute of Technology (MIT) and continued at Argonne, ^{226}Ra in the skeletal remains of persons exposed to radium is determined by gamma-ray spectroscopy. As described elsewhere in this Annual Report,[1] the results of all gamma-ray measurements in vitro made at Argonne on 104 radium cases are now stored in two CHRIS computer files. With this large data base subject to computer-assisted analysis, it was thought appropriate to do a more extensive study of the distribution of radium in bone than reported earlier,[2] when only four cases were available for analysis, and to compare our results with those of MIT for the cases measured at both laboratories. Methods and results are presented below.

The Distribution of ^{226}Ra in Human Bone

Method

To provide a reasonable geometry for gamma-ray counting the prepared bones are divided into several small groups before measurement. By standardizing the composition of the groups we reduce the number of correction factors required in the calculation of radium content and are able to elicit additional information about the bones themselves. One such piece of information is the ratio of the concentration of radioactivity in the bone (which we loosely call the specific activity) to the estimated average concentration ("specific activity") for the entire skeleton.

In the earlier investigation we looked for a relationship between the specific activity ratio (SAR) and type of bone structure. This information is important to bone modeling studies. We observed that bone with predominantly cancellous structure usually had a ratio greater than unity, i.e., its specific activity was greater than the average for the skeleton, while the ratio for bone of a more compact character had a value less than unity.

Currently there is information stored in the computer for 104 radium cases measured in vitro, but this includes some cremains and autopsy specimens. Imposition of restrictive criteria reduced to 19 the number of cases applicable to the investigation of SAR. The five criteria for a suitable sample were as follows: 1) more than 50% of the entire skeleton, 2) tissue-free bones, 3) standard grouping of bone or bone parts, 4) sufficient ^{226}Ra content, and 5) no evidence of leaching.

The skeleton is generally divided into 20 standard groups of bones, which have been described previously.[3] However, the composition of groups for many cases is nonstandard because of incomplete skeletons, use of more bones per group for low-activity cases, or work having been done before the composition guidelines were established.

In this study the contents of each group containing long bones or long bone parts had to be 95% complete, while for all other groups the minimum requirement was 55% complete. The minimum skeletal content of ^{226}Ra was set at 85 nCi to minimize the contribution from the statistical errors of counting. The nature of the specific activity ratio makes it very sensitive to leaching of bone mineral by ground water. Consequently, cases with bones exhibiting significant leaching were rejected. Three of the original four cases are included in the present study.

Results

The geometric means of the SAR's for the various groups are shown in Figure 1 in order of decreasing SAR. All 19 cases are not represented in every group. In fact, 3 groups are represented by only 8 cases. The overall results agree with our earlier observations, except for a minor reordering of groups. The values of the ratios are slightly lower, probably owing to use of the geometric mean in the present work; for groups in which the number of cases exceeded 15, the distribution of values tended to be lognormal. The variation of SAR within some groups is still large, especially where the ratio is greater than unity. An exception is the group containing innominates. A large variation within a group means that the calculation of skeletal content of radium, based only on that group, is made with less confidence.

The distribution of radium in the human skeleton may be dependent on factors such as type of exposure, age at first exposure, duration of exposure, time elapsed since intake, total amount of radium, and variations in bone metabolism within the individual and between individuals. A class-dependent pattern of ratios among groups was observed at MIT[4] for 3 classes of individuals, based on exposure type (and, coincidentally, on age at exposure and length of time during and after intake). In Figure 2 we show the ANL values of the mean ratios by groups for four classes of individuals: 5 dial painters, 3 Radithor drinkers, 6 laboratory workers, and 5 who received radium injections. Because of the small sample size the arithmetic mean is used, rather than the geometric mean. It is difficult to say that there is any real difference in pattern between classes.

Conclusions

The present work confirms observations that we reported earlier.[2] The wide variation in specific activity ratios, especially among the cancellous bone groups, is real and not just the result of a small sampling. More radium cases which meet our restrictive criteria would be needed to establish the relation between the distribution of radium in bone and exposure parameters and to determine the significance of the variation of specific activity ratios within bone groups.

Comparison of Results from MIT and ANL

Methods of preparing and sealing bones or bone groups for γ-ray measurements at MIT and the results of these measurements have been reported.[4–6] Saved specimens from some of these cases and more detailed reports from MIT on individual bone groups are now at CHR-ANL. The majority of these specimens have been measured by us, using the method described in a previous paper,[2] and an interlaboratory comparison of the ^{226}Ra determinations

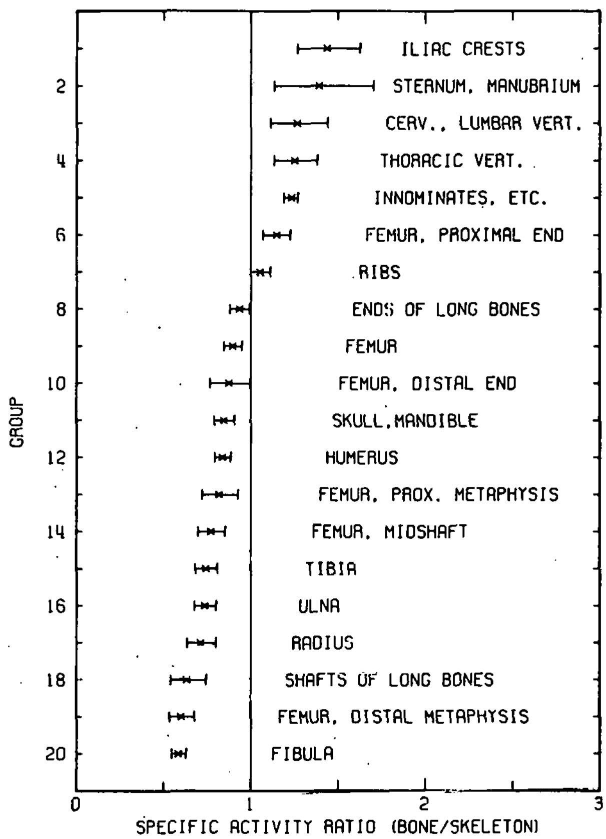

FIG. 1.--Geometric mean specific activity ratio, with standard error, for each of the bone groupings.

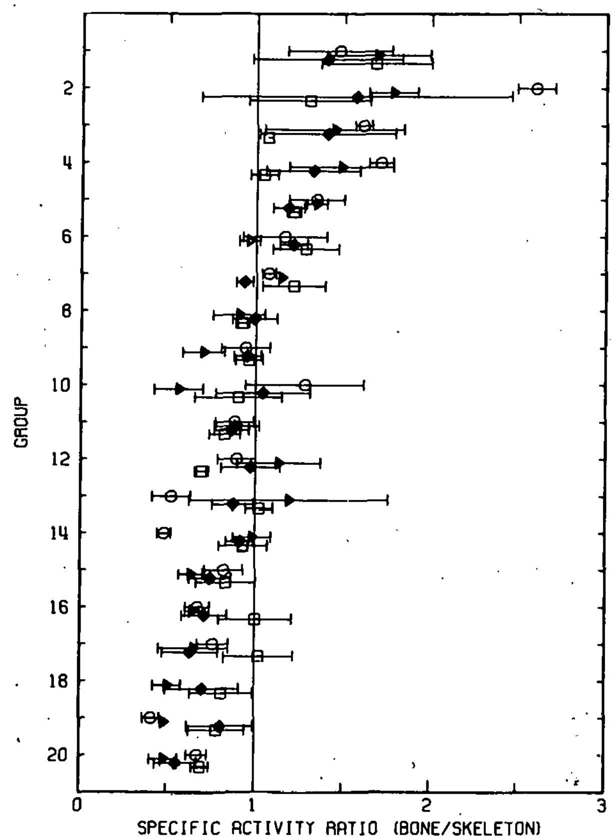

FIG. 2.--Arithmetic mean specific activity ratio, with standard error if > 0.03, differentiated by ^{226}Ra exposure type: o = dial painter, ▲ = drinker, ◆ = subject of injections, and □ = laboratory workers. Bone groups are listed in same order as in Figure 1.

is presented in Table 1. Because of the difference between laboratories in grouping bones for γ-ray measurement, only those 5 groups shown in Table 1 were suitable for comparison. Samples which were not identical at MIT and ANL were excluded. The first column under each group gives a direct comparison of the ^{226}Ra content reported by the two laboratories. It is evident that for the longer bones ANL finds consistently higher levels than MIT. This discrepancy can be largely resolved by taking into account the methods of calculation. The group at MIT did not make corrections for differences in absorption and geometry between the sample and the ^{226}Ra standard, but

Table 1. Comparison of γ-Ray Measurements of ^{226}Ra in Bone

Bone group	Skull or Skull + Mandible			Humerus			Radius + Ulna			Femur			Tibia + Fibula		
Case No.	Ratio[a]	Relative error, %[b]	Matched ratio[c]	Ratio[a]	Relative error, %[b]	Matched ratio[c]	Ratio[a]	Relative error, %[b]	Matched ratio[c]	Ratio[a]	Relative error, %[b]	Matched ratio[c]	Ratio[a]	Relative error, %[b]	Matched ratio[c]
00-006	1.038	2.70	1.048	0.875	5.94	0.931	0.933	4.61	1.011	1.040	2.79	1.143	0.942	2.87	1.027
00-009							1.045	4.12	1.004				0.938	2.99	1.017
00-020				0.967	6.31	1.028	1.051	5.71	1.000	0.890	3.03	0.978	0.957	3.45	1.023
01-003	0.870	3.79	0.881	0.981	5.00	1.008	1.026	4.58	1.031				0.833	4.92	0.864
01-010	0.973	2.67	0.983	0.955	5.76	1.016	1.064	3.76	1.008						
01-011				0.943	5.73	1.003	0.941	3.83	0.944				0.914	3.17	0.973
01-019	1.079	3.71	1.090	1.184	11.4	1.260	0.966	13.5	0.903				0.859	7.33	0.929
01-033				1.022	6.46	1.087									
				1.043	6.33	1.110									
01-052	1.014	2.78	1.024				1.000	7.20	0.947	0.897	2.34	0.908	0.944	5.30	1.013
01-054	0.964	2.70	0.974	0.907	10.4	0.965	1.071	4.67	1.017				0.953	3.36	0.962
01-115	0.946	3.17	0.956										1.015	4.24	1.101
01-132	1.007	2.88	1.017	0.905	6.19	0.963							0.849	3.30	0.924
01-145	1.034	2.61	1.044	0.937	5.55	0.997	1.000	4.00	0.941				0.919	2.61	0.981
01-388	0.967	2.69	0.977	0.916	5.79	0.974	0.950	4.21	0.912	0.952	2.73	0.964	0.873	2.86	0.941
01-390	1.005	3.68	1.018	1.032	6.20	1.060	1.015	8.08	1.009	0.980	5.20	1.017	0.857	6.77	0.883
01-404										0.902	2.77	0.991			
	1.020	2.84	1.030				1.106	3.44	1.139	0.954	2.10	0.971			
01-434	0.782	4.86	0.792	0.950	5.26	0.976	1.059	6.04	1.047				0.839	5.01	0.863
01-438	1.013	2.86	1.023	0.985	6.70	1.048	1.083	4.62	1.030				0.886	3.39	0.946
01-439				1.200	13.2	1.277				0.966	5.49	0.966			
01-485				1.044	7.66	1.110	0.950	7.37	0.905				0.972	4.84	1.054
01-562	0.984	3.55	0.992	0.982	4.58	0.995									
01-568	0.947	4.85	0.959	1.000	8.70	1.027	1.159	9.32	1.138						
01-574	0.996	2.81	1.006												
01-578	0.922	2.60	0.931	0.946	6.66	1.006	1.134	7.23	1.078				1.024	4.00	1.091
09-041	0.863	5.21	0.872	1.030	14.9	1.096	0.758	11.3	0.758	0.718	5.29	0.789	0.869	5.87	0.934
09-084				0.839	7.99	0.893									
09-105				0.894	5.93	0.951	0.960	3.75	0.953						
Weighted mean	0.976		0.986	0.956		1.006	1.011		0.991	0.924		0.968	0.914		0.975
±S.E.	±0.014		±0.014	±0.013		±0.013	±0.016		±0.016	±0.024		±0.026	±0.012		±0.014

[a] $\frac{\text{nCi/bone group (measured at MIT)}}{\text{nCi/bone group (measured at ANL)}}$

[b] Error used to weight ratios (see text)

[c] Ratio (a)/ correction factor used at ANL (see text and Table 2)

assigned an additional 7% error for these uncertainties,[5] while we determined a correction factor for each bone group. This factor is defined as

$$\frac{(\text{cpm/nCi})_{\text{bone group}}}{(\text{cpm/nCi})_{^{226}\text{Ra source}}},$$

and it varies with bone group, geometry, and ^{226}Ra source. Variation in the degree of attenuation within bone groups was observed to be small ($\approx$ 5%) for three skeletons of widely differing size; the effects of this variation were included in the error of precision of the results.

When this refinement is not applied to our data, the resulting ratios, shown as "matched ratio" in column 3 for each group, are no longer significantly different from unity. However, it still appears that we are counting the longest bones (femur, tibia) with a higher efficiency relative to a ^{226}Ra standard than MIT. Any systematic error, such as uncertainties in the content of the ^{226}Ra standard used at each laboratory, would be independent of sample size.

Column 2 for each group shows the errors of precision determined for the ANL measurements. These values were used as convenient weighting factors in determining the mean ratio; the overall error for each ratio is not shown, but it would include the counting and 7% assigned errors from MIT, and a 2% systematic error from ANL.

Typical correction factors used for each bone group are shown in column 3 of Table 2. These vary for bones not sealed in a normal grouping, but they are within the same range (0.91–1.07). Applied to the whole skeleton, these factors result in a 5% increase in the ^{226}Ra content compared to determinations in which geometry and absorption corrections have not been made. Thus the whole-body contents of ^{226}Ra determined in vitro and reported by MIT seem to be low by about 5%, which is still within their assigned error of 7%.

Estimation of ^{226}Ra Body Contents from Measurements on Partial Skeletons

A large number of the bone samples available to us came as saved specimens from complete, or nearly complete, skeletons which had been previously measured at MIT. By comparing our γ-ray measurements on these

Table 2. Correction Factors (ANL)

Bone Group	Mean % skeletal weight	Correction factor[a]
Skull, mandible	14.7	0.99
Cervical vertebrae, lumbar vertebrae	5.1	0.93
Thoracic vertebrae	4.2	0.93
Sternum, manubrium, xiphoid	0.6	1.03
Ribs	6.4	0.96
Humeri[b]	6.9	0.94
Radii[b]	2.2	1.07
Ulnae[b]	2.6	1.04
Tibiae[b]	11.5	0.92
Fibulae[b]	2.4	0.94
Femur	9.6	0.91
Femur, cut into 5 parts	9.6	0.98
Innominates, hands, feet, sacrum, scapulae, clavicles, patellae, coccyx, hyoid	25.0	0.94
Weighted mean[c]		0.95

[a]Typical values

[b]In some cases, shafts and ends are canned separately; however, the effective factors do not differ appreciably from those for the whole bones.

[c]$\frac{\Sigma \text{ (normal correction factor} \times \text{\% skeletal wt.)}}{\Sigma \text{ \% skeletal wt.}}$

specimens with results obtained at MIT on complete skeletons, we were able to determine how well we could calculate a whole-body content of ^{226}Ra from a partial skeleton.

We calculate a ^{226}Ra body content whenever ≥ 50% of the skeleton is measured. The Bone and Dosimetry Group of CHR prepares an "estimate of missing parts" for all cases, based on the mean % skeletal weights shown in Table 2. From these figures and the specific activities of the available parts, we obtain the total skeletal weight and the amount of ^{226}Ra missing, assuming that the missing bone (part) has the same specific activity as a comparable, measured bone. For example, if both ulnae are missing, we can use the specific activity of the tibia, which typically is similar (Figure 1), to calculate the amount of radium expected in the ulna. A 20% error is assigned to the estimate

Table 3. ^{226}Ra Body Contents Calculated from Measurements on Partial Skeletons (≥ 50%)

	MIT Measurements				ANL Measurements				
Case No.	^{226}Ra (± S.E.)[a] in total sample (nCi)	Estimated fraction of whole skeleton	Estimated total skeletal weight (g)	Estimated ^{226}Ra content ± S.E.[a] (nCi)	^{226}Ra (± S.E.) in total sample (nCi)	Estimated fraction of whole skeleton[b]	Estimated total skeletal weight (g)	Estimated ^{226}Ra content ± S.E. (nCi)	$\left(\frac{\text{est. } ^{226}Ra \text{ (MIT)}}{\text{est. } ^{226}Ra \text{ (ANL)}}\right)/0.95$[c]
01-574	2730 ± 15	1.00	3252	2730 ± 15	1515 ± 40	0.50	3600	3400 ± 400	0.845
01-003	12800 ± 40	1.00	5914	12800 ± 40	7875 ± 185	0.55	6000	14600 ± 1400	0.923
01-115	472 ± ?	1.00	3464	472 ± ?	260 ± 7	0.55	3600	490 ± 45	1.014
01-054	2130 ± 20	1.00	2770	2130 ± 20	1260 ± 30	0.56	2950	2300 ± 200	0.975
01-132	1327 ± 10	1.00	6953	1327 ± 10	773 ± 17	0.56	4800	1400 ± 125	0.998
09-041	114 ± 2	1.00	3862	114 ± 2	85 ± 3	0.56	3650	150 ± 15	0.800
01-388	2580 ± 20	0.99	3275	2600 ± 20	1525 ± 35	0.57	3400	2750 ± 250	0.995
00-006	2410 ± 12	0.94	3780	2610 ± 60	1765 ± 40	0.62	3670	2800 ± 200	0.981
01-019	236 ± 5	0.97	3780	240 ± 5	179 ± 5	0.65	4000	275 ± 20	0.913
01-404	2750 ± 20	0.99	7085	2800 ± 20	1730 ± 40	0.67	6600	2650 ± 200	1.113
01-438	1606 ± 13	0.86	3780	1850 ± 20	1080 ± 30	0.69	3800	1875 ± 150	1.039
01-145	6331 ± 26	1.00	4571	6331 ± 26	6550 ± 150	0.94	4100	6950 ± 200	0.959
01-390	7410 ± 30	1.00	3787	7410 ± 30	7500 ± 200	0.96	3800	7750 ± 200	1.006
Mean ± S.E.									0.963 ± 0.023

[a]Counting errors only (see text).

[b]Estimated by Bone and Dosimetry Group.

[c]Mean correction factor for whole skeleton (see Table 2).

of ^{226}Ra missing, giving a maximum uncertainty of ~ 12% in the skeletal content for cases with 80 nCi or more.

Table 3 shows the ^{226}Ra skeletal content estimated from partial skeletons by the above method at ANL compared with that measured on more nearly complete skeletons at MIT. The ratios of results shown in the last column include a 5% correction for the difference caused by our use of the absorption and geometry factors described above. From Table 1 it is evident that some of the largest differences (09-041 and 01-404) arise from the measured values rather than the estimates of missing weight. The standard deviation as determined from the 13 cases is 8%, which is close to the overall error of ~ 12% described above.

If a case has never been measured for ^{226}Ra, an estimate of body content must be made from the available specimen, no matter how small. If 25 to 50% of the skeleton is present and has representative amounts of both compact and cancellous bone, a reasonably accurate estimate can be made with the assumption that the measured specific activity of the total sample is the same as that of the complete skeleton. Comparison with data from MIT indicates that when only 25% of the skeleton is available, the expected error is as high as 40%. This decreases to 15% as the fraction of skeleton available increases to 50%. When the body content is calculated from only one or two bone groups, larger errors are probable, since data on specific activity ratios indicate standard deviations of 60% or more for some bone groups.

References

1. M. A. Essling and D. R. Huff, Computer storage of data obtained in the measurement of radium in vitro, this report.
2. M. A. Essling, A. T. Keane, and D. R. Huff, Measurements of ^{226}Ra in human bones, Radiological and Environmental Research Division Annual Report, July 1971–June 1972, ANL-7960, Part II, pp. 180–185.
3. J. E. Farnham and K. A. Rybicki, The preparation of skeletal remains, Radiological and Environmental Research Division Annual Report, July 1971–June 1972, ANL-7960, Part II, pp. 206–221.
4. M. R. Lewis, A. M. Noren, J. F. Foley, D. L. Gunner, and A. T. Keane, MIT Radioactivity Center Annual Report on Radium and Mesothorium Poisoning, MIT-952-5, Part II, pp. 514–516 (1968).

5. MIT Radioactivity Center Annual Report on Radium and Mesothorium Poisoning, MIT-952-2, pp. 18–31 (1965).
6. MIT Radioactivity Center Annual Reports on Radium and Mesothorium Poisoning, MIT-952-1 (1964), MIT-952-3 (1966), MIT-952-4 (1967), MIT-952-5, Part I (1968), MIT-952-6 (1969), MIT-952-7 (1970).

METHODS FOR THE ASSAY OF PLUTONIUM IN VIVO: WHAT ARE THE ALTERNATIVES?*

J. Rundo, M. G. Strauss,† I. S. Sherman,† and R. Brenner†

Methods for the assay of plutonium in the human body (especially in lung) are divided into indirect and direct methods. Indirect methods are bioassay and application of Langham's equation for daily urinary excretion as a function of time, and the use of the ^{241}Am usually present in plutonium as a γ-ray (60 keV) tracer. Problems and limitations of these two methods are discussed.

Direct methods are those in which radiation from the plutonium itself is measured. The current method is based on the assay of the characteristic L x rays of uranium (~ 17 keV). Even after attenuation by about 5 cm of soft tissue, these are still the most intense quanta emitted by ^{239}Pu, and they offer the only possibility for assaying it in vivo via its photon emissions. The limit of detection is still a substantial fraction of the maximum permissible lung burden. A study of the feasibility of determining plutonium by fluorescence K x-ray spectrometry, shows that the method offers no advantage over the uranium L x-ray method, although it is demonstrated that the K x rays of plutonium (absorption edge at 121.72 keV) can be excited by the 121.97-keV γ rays from ^{57}Co.

Three methods involving the induced fission of plutonium are discussed. These involve collection and measurement of the exhaled fission product gas ^{138}Xe, measurement of prompt fission γ rays, and measurement of delayed neutrons or the secondary effect of the 2.23-MeV γ rays resulting from their capture in hydrogen. The second method may be ruled out by the interference from γ rays resulting from radiative capture of some of the irradiating neutrons by hydrogen in the body, but the first and third methods offer a good deal of

---

*Summary of paper presented at Workshop on Measurement of Heavy Elements In Vivo, Battelle Seattle Science Center, Seattle, Wash., June 24–25, 1976.

†Electronics Division.

specificity. Neutron doses in the region of 0.1 to 1.0 rem would be needed, and the methods might be practical if relatively low energy (10 keV) neutrons could be used. A great deal of experimental work needs to be done before the feasibility of the method can be determined, and there remains the question of the ethics of irradiating personnel with neutrons in order to measure plutonium burdens.

THE USE OF ^{103}Pd AS A CALIBRATION SOURCE FOR THE DETERMINATION OF ^{239}Pu IN VIVO

R. E. Toohey

As one component of "mock plutonium," ^{103}Pd is frequently used as a calibration source for the determination of ^{239}Pu. Some considerations involved in its use are discussed; it is shown that the plutonium calibration curve derived from ^{103}Pd agrees well with that from ^{238}Pu.

Several questions arise concerning the use of ^{103}Pd as a calibration source for plutonium. Although the energies of the rhodium K_α and uranium L_γ x rays are identical at 20.2 keV, what is the effect of the rhodium K_β line at 22.8 keV? Is a source uniformly distributed in the lung an infinitely thick x-ray source? What are the effects of backscattering? How does one derive calibration factors for plutonium from data obtained from ^{103}Pd?

We have recently participated in an intercalibration experiment sponsored by the Mound Laboratory of Monsanto Research Corporation, Miamisburg, Ohio, in which participants in the earlier "mock Pu" experiment[1] verified their calibrations for ^{103}Pd. In addition, answers to the above questions were obtained. All measurements of the rhodium K x rays resulting from the decay of ^{103}Pd were made with an 18-cm diameter xenon-methane filled proportional counter. The ^{103}Pd sources were all in the form of the chloride dissolved in HCl. A point source consisted of 3.4 μCi of activity sealed between two pieces of mylar in an aluminum frame. A distributed source was prepared by adding about 3 μCi of ^{103}Pd in 10 ml of solution to Rando lung stock, then molding the lung stock in the form of an 11.4-cm diameter cylinder which was subsequently sectioned into five slabs 2.5 cm thick.

The point source was counted under successive layers of tissue-equivalent material and the resulting spectra were fitted with gaussian peaks. With no absorber present, the K_β line contributed 11% of the total counts. Because of greater relative absorption of the K_α line, this contribution increased to 23% when the source was counted under 6 cm of absorber. However, the energy band of the analyzer can be set just above the K_α line, since the two are nearly resolved, and this technique eliminates 70% of the counts from the K_β line. Thus the latter accounts for 3 to 7% of the x-ray counts observed in the K_α band as 0 to 6 cm of absorber are placed over the source.

In order to determine if the lung represents an infinitely thick source of these x rays, the proportional counter was inverted and successive layers of the ^{103}Pd-loaded lung stock were placed directly on the window. The results are shown in Figure 1. It is apparent that after about 12 cm, the counting rate becomes constant. Thus, since the lungs are some 15 cm thick in an average person, a source distributed throughout the lung is indeed infinitely thick, minimizing the effects of source geometry.

One must be careful when comparing the responses due to x rays from point sources and from distributed sources to allow for the effects of backscattering. If the point source is electrodeposited on stainless steel, for example, there will be almost no backscattering. If the source is distributed in or mounted on low-Z material, backscattering becomes important. Figure 2 shows the ratio of counts observed in the peak with and without backscattering material behind the point source, as the source is covered with absorber. The contribution of backscattered photons ranges from 8 to 5% and is certainly not negligible.

Finally, if ^{103}Pd is to be used as a calibration source for plutonium, the calculation of plutonium counts expected from ^{103}Pd counts observed must be verified. The following formula is used to convert rhodium K_α counts/min/unit activity to counts/min/unit activity expected in the uranium L_β and L_γ peaks following the α-decay of ^{238}Pu:

$$^{238}\text{Pu cpm} = {}^{103}\text{Pd cpm} \times \frac{1}{0.72} \times [0.0596 \times 1.375 \times \exp(-0.32d) + 0.0124] ,$$

where

0.72 is the K_α abundance per decay of ^{103}Pd

0.0596 + 0.0124 are respectively the L_β and L_γ abundances per decay of ^{238}Pu [2]

1.375 is the relative efficiency of the proportional counter at 17.2 keV vs. 20.2 keV,

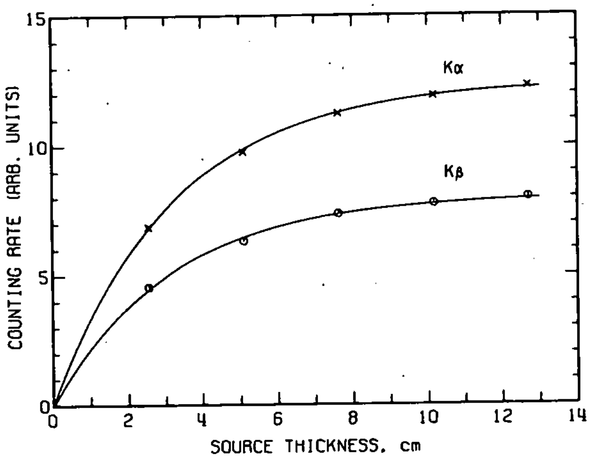

FIG. 1.--Determination of infinite source thickness for a distributed source of ^{103}Pd

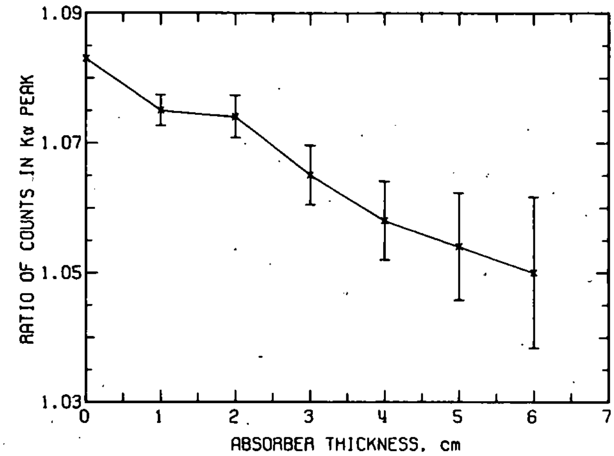

FIG. 2.--The effect of backscattering material behind the source on the observed counting rate in the K_{α} peak following ^{103}Pd decay

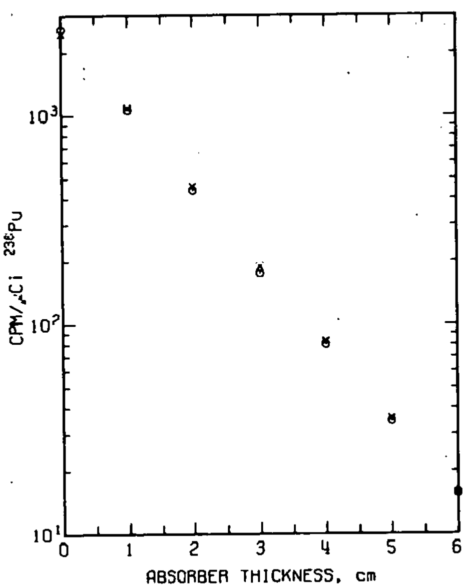

FIG. 3.--Calculated (x) and observed (o) counting rates for ^{238}Pu as a function of absorber thickness. The calculated counting rates were derived from the observed counting rates of ^{103}Pd as described in the text.

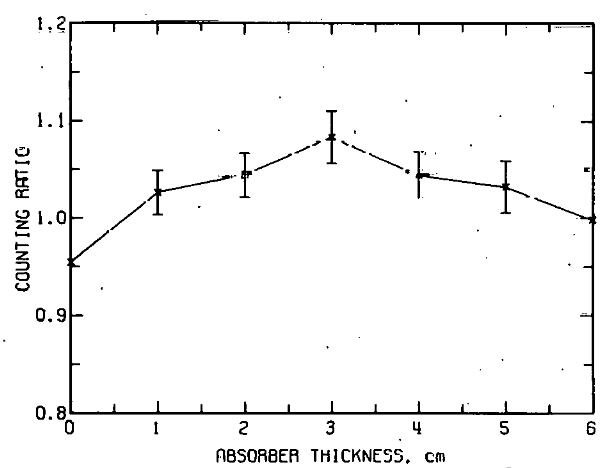

FIG. 4.--The ratio of calculated to observed counting rates for ^{238}Pu as a function of absorber thickness. The apparent trend in the data is unexplained.

0.32 is the difference in attenuation coefficients of tissue at the two energies, and

d is the thickness of tissue-equivalent absorber over the source.

Note that because the rhodium K_α and uranium L_γ lines have the same energy, efficiency and attenuation corrections are unnecessary for the L_γ line.

Figure 3 shows the observed and calculated counting rates for ^{238}Pu as a function of overlying absorber thickness. The ratio of calculated to observed counts is shown in Figure 4. Although the ratio becomes as high as 1.08, the overall agreement is adequate within statistical error. Thus it has been demonstrated that ^{103}Pd may be successfully used as a calibration source for the determination of plutonium.

References

1. J. Rundo, K. F. Eckerman, R. E. Toohey, and M. A. Essling, The measurement of "mock plutonium" in vivo, Radiological and Environmental Research Division Annual Report, July 1972—July 1973, ANL-8060, Part II, p. 228.
2. R. E. Toohey, Relative abundances of uranium $L_{\alpha,\beta,\gamma}$ conversion x rays following the α-decay of plutonium, this report.

RELATIVE ABUNDANCES OF URANIUM $L_{\alpha,\beta,\gamma}$ CONVERSION X RAYS FOLLOWING α-DECAY OF PLUTONIUM*

R. E. Toohey

The uranium conversion L x-ray yield per alpha-particle decay of plutonium must be known in order to calibrate a detection system for the assay of plutonium in vivo. The total L x-ray yields for the various Pu isotopes are well known.[1] However, there are four major subgroups of L x rays, and the yield of each subgroup must also be determined. In addition, each subgroup is composed of several lines. The uranium L x-ray spectrum from a ^{238}Pu source is shown in Figure 1.

The abundances of the subgroups must be known for several reasons: (1) the lower energy L_ℓ and L_α lines usually do not escape from the body, thus only the L_β and L_γ subgroups are observed in measurements made in vivo; (2) ^{238}Pu, because of its higher specific activity and x-ray yield per α is often used to calibrate for ^{239}Pu; (3) observation of the differing attenuation of the resolved subgroups can offer a method for determining the effective depth of material deposited in the body; (4) in an actual contamination incident one is usually dealing with a mixture of several isotopes; and (5) new semiconductor detectors capable of resolving the subgroups are now being evaluated for the assay of plutonium in vivo. When the experimental work reported here was nearly complete, a paper on this subject was presented at a scientific meeting by a group from Oak Ridge National Laboratory.[2] We are, therefore, able to compare our results with those from Oak Ridge.

Sources of ^{238}Pu, ^{239}Pu, ^{240}Pu, and ^{242}Pu were electrodeposited on silver disks; each source had an activity of about 1 μCi. The ^{242}Pu source contained 24.5% ^{238}Pu and 2.5% ^{239}Pu by x-ray activity, and the contributions of these two isotopes were taken into account in the data analysis. The other sources were essentially isotopically pure. Each source was placed

---

*Summary of a paper presented at the 21st Annual Meeting of the Health Physics Society, San Francisco, California, June 28–July 2, 1976.

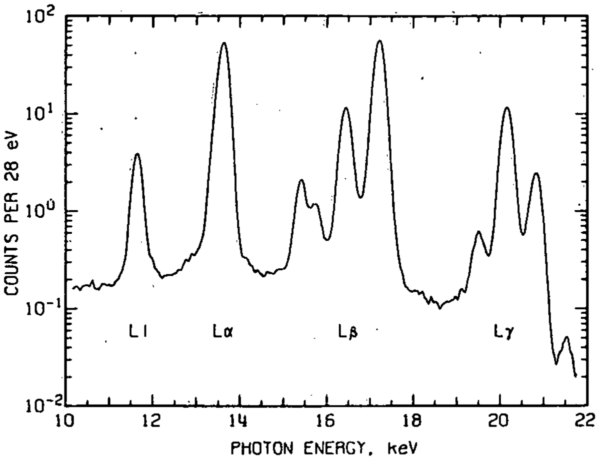

FIG. 1.--The uranium L x-ray spectrum from ^{238}Pu obtained with a Si(Li) detector.

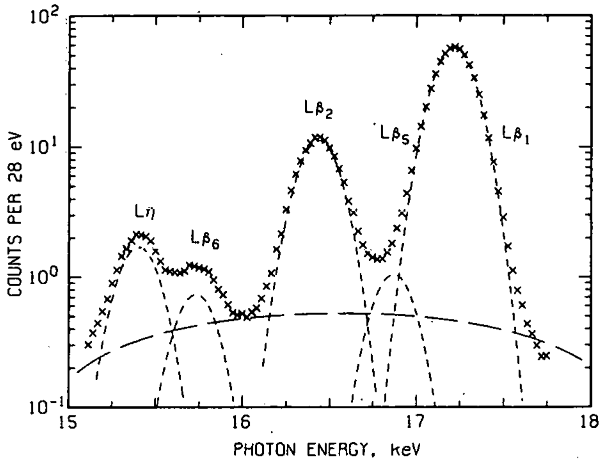

FIG. 2.--The uranium L_β subgroup from ^{238}Pu. The experimental points are shown by (x) and the gaussian peaks and polynomial background fitted to the points are shown by dashed lines.

Table 1. The x-ray yields obtained in this experiment, compared with those from Refs. 2 and 5. The total yields were normalized to those of Ref. 2. The standard deviations are omitted for ease of reading. They are 1 to 2% on the ORNL and AERE-H data and 5% on the ANL data, owing largely to the difficulties in detector calibration mentioned in the text.

Pu ISOTOPE	$\sum L$ (%/α)	L_ℓ	L_α	L_β	L_γ
ANL (this work)					
238	11.4	0.24	3.97	5.96	1.24
239	4.6	0.08	1.42	2.64	0.46
240	10.1	0.21	3.51	5.21	1.17
242	8.5	0.17	3.08	4.28	1.02
ORNL (Ref. 2)					
238	11.4	0.26	4.15	5.61	1.36
239	4.6	0.11	1.82	2.16	0.53
240	10.1	0.24	3.78	4.84	1.20
242	8.5	0.21	3.10	4.15	1.08
AERE-H (Ref. 5)					
239	4.6	____	1.67	2.38	0.55

2 mm from the face of a 10-mm^2 Si(Li) detector having a 0.127-mm thick beryllium window, and the x rays were counted for 1000 min. The spectrum in Figure 1 was obtained in this way. Each subgroup was then fitted with overlapping gaussian peaks on a polynomial background. The number of peaks and the order of the polynomial were supplied as input data to the computer code FATAL,[3] which then determined the positions, heights, and (constant) resolution of the peaks, and the coefficients of the polynomial by the method of least squares. An example is shown in Figure 2. The peak areas were obtained by integrating the gaussians, and the areas were summed to give the yield for each subgroup.

The detector was calibrated by the standard technique of measurement of the conversion x-ray yield of ^{241}Am.[4] The total x-ray yields of the plutonium isotopes were normalized to those reported from the Oak Ridge National Laboratory,[2] and the individual yield of each subgroup was then calculated. The results are presented in Table 1 and compared with the Oak Ridge results and a result obtained at Harwell.[5]

The source of ^{241}Am used to calibrate the detector was mounted between thin silver and gold foils, and the silver K x rays and gold L x rays excited by the 60-keV γ ray of ^{241}Am interfered with the analysis. Consequently, our results in Table 1 may be revised slightly when the detector has been calibrated with a source of ^{241}Am mounted in identical fashion to the plutonium sources. Nevertheless, the general agreement of our results with those obtained by others is satisfactory.

Acknowledgements

The author wishes to thank E. T. Kucera of the Chemical Engineering Division for preparing the plutonium sources.

References

1. K. L. Swinth, Battelle Pacific Northwest Laboratory Report BNWL-1648 (1972).

2. C. E. Bemis, R. E. Goans, W. M. Good, and G. G. Warner, Detection of Internally-Deposited Actinides, Part IV: Preliminary Considerations in the use of Large Planar Intrinsic Ge Detectors, Ninth Midyear Topical Symposium of the Health Physics Society, Denver, Colorado, February 9–12, 1976.
3. L. Salmon and D. V. Booker, United Kingdom Atomic Energy Authority Report AERE-R7129 (1972).
4. J. L. Campbell and L. A. McNelles, Nucl. Instrum. Meth. 125, 205 (1975).
5. D. Newton, AERE, Harwell, 1975, private communication.

PROGRESS REPORT ON THE DEVELOPMENT OF THE FISSION TRACK METHOD FOR THE DETERMINATION OF PLUTONIUM IN BIOLOGICAL MATERIALS

R. P. Larsen and R. D. Oldham

In the development of the fission track method for the determination of plutonium, work has been concentrated on the problem of reducing the amount of uranium associated with the plutonium at the time of neutron irradiation. A value of 1.0 ± 0.5 fg plutonium equivalent for the uranium blank has been obtained, so the lower limit for the amount of plutonium that can be determined in a sample is about 5 fg (0.3 fCi).

An analytical method is being developed for the determination of plutonium in biological materials in which fission track counting is the method of detection. This method is potentially four orders of magnitude more sensitive than the radiochemical methods. The plutonium is separated from the other constituents of the sample, deposited within an area of 2 to 3 mm^2 on a polished surface, covered with a thin sheet of Lexan, and irradiated with thermal neutrons. After the irradiation, the Lexan is etched with a potassium hydroxide solution, and the number of fission tracks is counted by viewing the Lexan at a magnification of 100 × to 200 ×. An intensive review of the method was given in a previous Annual Report.[1]

In the development of the fission track method the objective has been the capability of determining with an accuracy of ± 25% the urinary excretion rates of individuals whose only exposure to plutonium has been that due to fallout. As this rate is estimated to be one fg/day (0.06 fCi/day), the blank for the procedure must have a plutonium equivalent (P.E.) of 0.2 fg or less. The blank is due to fission of uranium that is associated with the plutonium at the time of the neutron irradiation. The P.E. of 40 fg of natural uranium is 0.2 fg. The sources of uranium are the sample, the surfaces of containment vessels, the reagents used after the separation procedure to mount the plutonium, and contamination from the laboratory atmosphere introduced into the system during the mounting operation. A procedure has been devised which adequately separates the uranium in the sample from the plutonium,[2] a set of operating conditions has been established which forestalls introduction of uranium from the atmosphere, and it has been demonstrated that the reagents being used in the mounting operation are free of uranium.

An extensive evaluation was made of an electrodeposition technique for mounting the plutonium. The solution from the final step in the chemical separation procedure is converted to a sulfuric acid medium by fuming; the solution is diluted with water and neutralized to a pH of 2.0 with ammonia gas, and the plutonium is electrodeposited. The area of deposition is limited to about 2 mm^2 by the use of a mask; the operation is carried out in a vessel fabricated from Supersil (a high-purity quartz), and the anode in the electrodeposition is platinum. The percentage of the plutonium deposited ranged from 80 to 90%; the deposition was both uniform, as established by the fission track distribution in subsequent irradiations, and free of other solids, as established by the high resolution obtained when alpha spectrometric measurements were made of ^{238}Pu deposits.

The blank in the electrodeposition technique was determined with reagents that had been individually tested and demonstrated to contain negligible amounts of uranium. Relatively large amounts were evaporated to dryness, the residue was irradiated in contact with Lexan, and the fission tracks were counted. The plutonium equivalent value for this blank was 2.2 ± 1.0 fg. Because this blank is only a factor of 10 higher than that required for the analysis and quite reproducible and because the apparatus is very simple in design, it appeared that establishing the source of the uranium would not be difficult and that very probably a simple modification in the apparatus or procedure would solve the problem. A wide variety of experiments was devised and carried out for this purpose, but the source of the uranium could not be established. As repeated electrodepositions from the same solution gave blanks of the same magnitude, it appeared that uranium was being introduced into the system during the operation from either the platinum anode, the walls of the cell, or the surface of the mask in contact with the solution. The use of other platinum for the anode, including a piece that was known to have been refined prior to 1940, did not change the blank.

Dissolution of uranium from the surface of the cell (Supersil) or the mask (Mylar) and subsequent deposition on the exposed nickel appeared to be highly unlikely since both materials had been irradiated in contact with Lexan, and the resultant fission track density indicated that the concentration of uranium in each was very low. Nevertheless, an experiment was tried in which protracted contact of the cell with the electrolyte was followed by electrodeposition. The blank obtained in this experiment was no higher than that obtained when the electrodeposition was carried out immediately.

Failure to resolve the blank problem in the electrodeposition mounting technique prompted reevaluation of a mounting technique in which the solvent containing the plutonium is evaporated. Previous attempts to use this technique had resulted in plutonium depositions that were so localized that the counting of fission tracks was precluded. A different approach gave significantly better results. The 500 μl of 9 M hydrobromic acid from the last ion exchange column in the separation procedure is evaporated to about 50 μl in a Supersil container, transferred into a dimple formed on a sheet of Mylar and evaporated to dryness. The plutonium is dissolved in 10 μl of 0.9 M HBr, the solution is drawn into a 10 μl Eppendorf pipet, and delivered onto the nickel surface in increments of about 1 μl. After each increment the solution is evaporated to dryness. The evaporation is carried out at 60 C and the time required to complete the transfer is about 10 min. The deposition area is limited to about 3 mm^2 by a mask. (A 2-mm diameter hole is punched in a 0.1-mm thick sheet of heat-seal Mylar, and the sheet is sealed to the nickel surface.) When the transfer is completed the mask is peeled from the surface. Recovery in the entire operation is about 90%. Within the area outlined by the mask the plutonium is not uniformly distributed. It concentrates in a band along the periphery. However, there are no localized areas of high concentration, and it is estimated that the number of tracks that could be counted without significant loss due to coincidences is about 3000. This is more than the number required for the analytical method.

The blank for this mounting technique is a P.E. of about 1 fg, or about a factor of two better than that obtained by electrodeposition. In view of the fact that we have been unable to obtain blanks that are less than this, the applicability of the fission track method will be limited to samples containing 5 fg or more of plutonium.

References

1. R. P. Larsen and R. D. Oldham, Development of a method for the determination of fallout plutonium in tissue, Radiological and Environmental Research Division Annual Report, July 1973–June 1974, ANL-75-3, Part II, pp. 142–149.
2. R. P. Larsen and R. D. Oldham, Anion exchange separation of plutonium in hydrochloric and hydrobromic acid media, Talanta 22, 577–580 (1975).

X-RAY SPECTROMETRIC DETERMINATION OF THORIUM IN BONE AND OTHER BIOLOGICAL MATERIALS

R. P. Larsen and P. W. Umezis*

An x-ray spectrometric method has been developed for the determination of thorium in bone and other biological materials. The limit of detection at the 95% confidence level is 20 ng. This corresponds to a concentration of 2 ppb in a 10-g sample of bone ash.

An x-ray spectrometric method with very high sensitivity has been developed for the determination of thorium in bone. The bone is ashed, dissolved in acid, a known amount of ^{234}Th (half-life 27 days) activity is added, and the thorium is separated from the other sample constituents. Separation from phosphate is effected by precipitating about 10% of the calcium as the oxalate; this carries nearly all of the thorium. The calcium oxalate is dried and is converted at 600 C to calcium carbonate, which is then dissolved in nitric acid. The solution is passed through a Dowex-1 anion exchange column. Thorium is strongly adsorbed; calcium and the other cations are washed from the column with strong nitric acid. The thorium is eluted with dilute hydrochloric acid and is then coprecipitated with 0.1 mg of ferric hydroxide by the addition of ammonium hydroxide. The ferric hydroxide is mounted and assayed in a secondary source, energy dispersive x-ray spectrometer. The amount of ^{234}Th in the mount is a measure of the thorium recovery in the separation procedure. It ranges from 70 to 80%. The detection limit is 20 ng, i.e., 2 to 3 ppb thorium in bone when the amount of ashed bone taken for analysis is 10 g. There appears to be no reason why this method cannot be used for the determination of thorium in liver and other soft tissues; the chemical separation procedure is very specific and there is far less inorganic material in soft tissues than there is in bone.

*Participant in Undergraduate Research Program, Center for Educational Affairs.

Preliminary studies of some former employees of a thorium refinery have demonstrated the presence of small amounts of thorium in the thorax of some of these persons. Calibration of external γ-ray counting is still incomplete, but in a few cases the amounts present appear to be in excess of 10 mg of thorium, as judged from the intensity of the 2.16-MeV γ ray.

A study of the distribution of thorium in such persons could provide information that would lead to a better understanding of the mechanisms by which plutonium is translocated from the lungs to other parts of the body. The physical properties of thorium and plutonium dioxides are nearly identical, and the solution chemistry of thorium is very similar to that of tetravalent plutonium, the oxidation state in vivo. The deposition sites for very small amounts of thorium are the same as those for plutonium, viz., the liver and the skeleton.

The sensitivity of the analytical method described above should be adequate for these studies. If 10% of the estimated thorium content were translocated to the liver and skeleton, the concentrations in these tissues might be in the ranges of 0.1 to 1 ppm and 0.01 to 0.1 ppm, respectively.

COUNTING CHAMBER FOR ALPHA-SPECTROMETRIC MEASUREMENTS

R. P. Larsen and R. F. Selman*

A surface barrier detector for the measurement of alpha activity must be operated in a chamber under vacuum, and the chamber must have a mechanism for positioning reproducibly the mounted activity relative to the detector. For nearly all of our determinations of alpha-particle emitting nuclides, the mount of the separated nuclide must be placed as close to the detector as possible because the amount of radioactivity is very small. It is highly desirable that provisions be made for protecting the face of the detector against contamination and/or damage, e.g., the mount contacting the detector and the inadvertent contact with a human finger. It has been our experience that none of the commercially available chambers as received can be depended upon to be vacuum-tight (indeed some have had to be reworked by our machinists); the mechanisms for positioning the sample are awkward to use and/or unreliable, and there is no provision in any of the chambers for protecting the detector.

A chamber that is not subject to these operational difficulties and that provides nearly fool-proof detector protection has been designed, and several of these chambers have been built and have been found to perform very satisfactorily. Figure 1 is a drawing of this chamber while Figure 2 shows four of the chambers mounted on a rack and connected to the vacuum manifold. All parts of the chamber save the separation ring are fabricated from 6061-T aluminum; the separation ring is made of 0.030-inch thick nylon sheet. To facilitate mounting the detector in the chamber, the length of the pin on the BNC vacuum feed-through connector is increased slightly. In the mounting operation the detector is slipped onto the pin to the point where the detector is just supported. It is then slipped into the chamber until the cover plate is in contact with the body of the chamber. Just prior to this contact, when the distance between the two is about 0.5 cm, the detector guard ring contacts the separation ring, and as the cover plate and chamber body are brought into

*Central Shops.

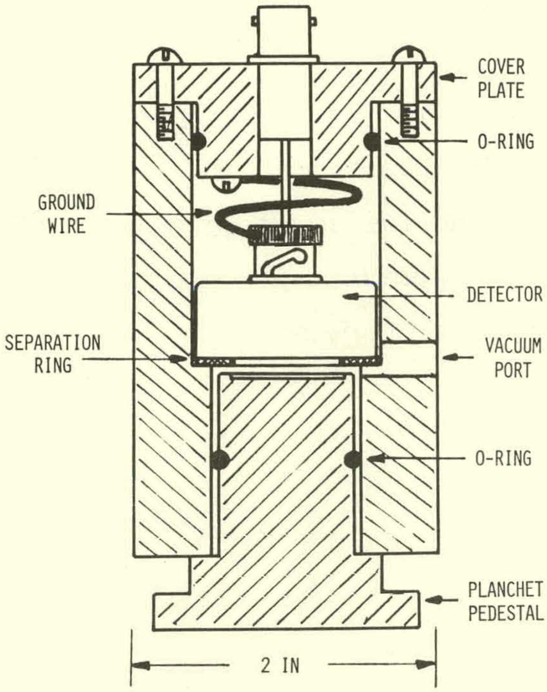

FIG. 1.--Alpha spectrometry chamber.

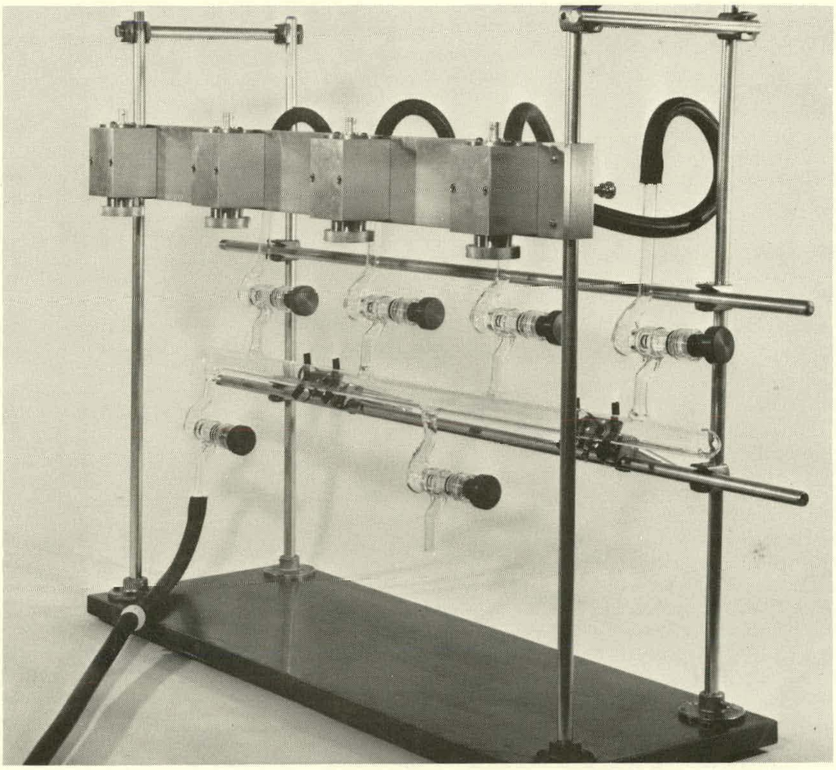

FIG. 2.--Alpha spectrometry system showing 4 mounted chambers and the associated vacuum manifold. (ANL neg. 149-76-211).

contact, the pin slips into the BNC connector on the detector to complete the bias connection.

To insure reliable grounding of the detector, one end of a flexible, insultaed wire is fastened to the cover plate and the other end to the detector. The detector end of the wire is soldered to the spring-loaded, locking mechanism from a BNC cable connector. Just prior to the operations described in the preceding paragraph, the ground wire is connected to the detector.

A MICROPROCESSOR-ASSISTED CALIBRATION FOR A REMOTE WORKING LEVEL MONITOR*†

W. P. McDowell,+ D. J. Keefe,+ P. G. Groer, and R. T. Witek+

A method of calibrating a Remote Working Level Monitor, an instrument designed to measure the working level and the Rn-daughter concentrations in the atmosphere, is described. The method uses the instrument's control microprocessor to calculate the β-efficiencies for RaB and RaC from the counts accumulated in the instrument's RaA, Ra(B+C) and RaC' channels. Two independent methods of determining the Rn-daughter concentrations require the processor to solve systems of linear equations with several unknowns. No assumptions about Rn-daughter equilibrium are necessary. Test results from several calibration runs in a uranium mine are presented.

*Work partially supported by the U.S. Bureau of Mines.

†Summary of a paper to be presented at the 1976 IEEE Nuclear Science Symposium, October 20–22, New Orleans, and to be published in the transactions.

+Electronics Division.

COMPUTER STORAGE OF DATA OBTAINED IN THE MEASUREMENT OF RADIUM IN VITRO

M. A. Essling and D. R. Huff

Data obtained in the measurement of radium in vitro at CHR-ANL are now entered into two CHRIS files. Currently, file BONES contains information pertinent to 961 groups of bone, representing 104 exhumed or willed cases. File SKEL contains summary data for each case.

Since the establishment of the Center for Human Radiobiology in 1969, the Body Radioactivity Measurements Group at Argonne has made gamma-ray measurements in vitro on 104 radium cases represented by willed bodies, exhumed remains, autopsy samples and cremation ashes. The results of these measurements are now collected into two CHRIS (Center for Human Radiobiology Information System) files, "BONES" and "SKEL". Although the files currently contain data from CHR-ANL only, they are structured to accept data from any laboratory.

For gamma-ray measurements, the skeleton is generally divided into 20 groups of standard composition. A group may consist of a single bone, a bone part, or a collection of bones or bone parts. File BONES contains information concerning these groups, including date and place of measurement, weight, ^{226}Ra content, fractional radon retention, specific activity (nCi/g of bone), relative specific activity (specific activity of bone relative to that of entire skeleton), and associated errors. The composition of many groups is not standard, however, because of incomplete skeletons or low activity, determined from a preliminary measurement of the whole sample. To permit meaningful comparisons of results, BONES contains the individual identification of each bone in the group and an indication of the fraction of bone present. Currently BONES contains data on 961 bone groups representing 104 cases.

File SKEL contains summary data relating to the available sample, and estimates for the entire skeleton, if sufficient sample is available. The date, place, and method of measurement, general condition of the sample, total weight, ^{226}Ra content, fractional radon retention, ^{228}Ra/^{226}Ra activity ratio (if determined), an estimate of the fraction of skeleton available for the measurements, and uncertainties are stored.

A code book for each of the files is available. It describes each field in detail and explains the various coded representations.

EXPANSION OF THE CHR BONE CODE SYSTEM

J. E. Farnham and R. A. Schlenker

This report describes the coding system used in the Center for Human Radiobiology (CHR) to identify individual bones and portions of bones of a complete skeletal system. It includes illustrations of various bones and bone segments with their respective code numbers. Codes are also presented for bone groups and for nonbone materials.

Introduction

The bone coding system used in CHR[1] has been expanded to include bone segments and bone groupings. The definitions of the original codes are not affected by the expansion except for slight changes in the meanings of A0 (skull) and A1 (mandible). This report describes the latter changes plus the additional codes. The original codes are included in the tables and figures.

Skull, Mandibles, and Innominates

A separate code has been assigned to each individual bone of the skull. Codes have been added for the edentulous skull and mandible. Note that A0 and A1 now identify the skull and mandible complete with all available teeth. Previously they designated the skull and mandible without implying anything about the teeth.

The individual bones of the innominates have been assigned separate codes to augment E6 and E7, the codes for the entire innominates.

The new codes for the individual bones have been formed from the codes A0, A1, E6, and E7 by adding a letter followed by a zero to the ends of these codes. Thus, A0A0 denotes the occipital bone, E6A0 denotes the ilium, etc. All original, altered, or additional codes referring to whole bones may be found in Table 1. Figures 1 and 2 associate most whole bone codes with diagrams of the bones.

The iliac crest is normally cut from each innominate for gamma-ray radioactivity measurement. The codes E6A3 and E7A3 are assigned to the right and left crests; E6D0 and E7D0 are assigned to the right and left

TABLE 1. Codes for whole bones

A0	- Skull, with teeth
A0Z0	- Skull, edentulous
A0A0	- Occipital
A0B0	- Parietal, l.
A0C0	- Parietal, r.
A0D0	- Frontal
A0F0	- Temporal, l.
A0G0	- Temporal, r.
A0H0	- Sphenoid
A0J0	- Ethmoid
A0K0	- Nasal, l.
A0L0	- Nasal, r.
A0M0	- Maxilla, l.
A0N0	- Maxilla, r.
A0P0	- Palatine, l.
A0Q0	- Palatine, r.
A0R0	- Inferior nasal concha, l.
A0S0	- Inferior nasal concha, r.
A0T0	- Vomer
A0V0	- Lacrimal, l.
A0W0	- Lacrimal, r.
A0X0	- Zygomatic, l.
A0Y0	- Zygomatic, r.
A1	- Mandible, with teeth
A1Z0	- Mandible, edentulous
A2	- Rt. clavicle
A3	- Lf. Clavicle
A4	- Rt. scapula
A5	- Lf. scapula
A6	- Manubrium
A7	- Sternum
A8	- Xiphoid
A9	- Lf. rib 6
B0	- Rt. rib 1
B1	- Lf. rib 1
B2	- Rt. rib 2
B3	- Lf. rib 2
B4	- Rt. rib 3
B5	- Lf. rib 3
B6	- Rt. rib 4
B7	- Lf. rib 4
B8	- Rt. rib 5
B9	- Lf. rib 5
C0	- Rt. rib 6
C1	- Cervical vertebra 1
C2	- Cervical vertebra 2
C3	- Cervical vertebra 3
C4	- Cervical vertebra 4
C5	- Cervical vertebra 5
C6	- Cervical vertebra 6
C7	- Cervical vertebra 7
C8	- Rt. rib 7
C9	- Lf. rib 7
D0	- Rt. rib 8
D1	- Lf. rib 8
D2	- Rt. rib 9
D3	- Lf. rib 9
D4	- Rt. rib 10
D5	- Lf. rib 10
D6	- Rt. rib 11
D7	- Lf. rib 11
D8	- Rt. rib 12
D9	- Lf. rib 12
E0	- Rt. humerus
E1	- Lf. humerus
E2	- Rt. radius
E3	- Lf. radius
E4	- Rt. ulna
E5	- Lf. ulna
E6	- Rt. innominate
E6A0	- Rt. ilium
E6B0	- Rt. ischium
E6C0	- Rt. pubis
E7	- Lf. innominate
E7A0	- Lf. ilium
E7B0	- Lf. ischium
E7C0	- Lf. pubis
E8	- Rt. patella
E9	- Lf. Patella
F0	- Rt. scaphoid
F1	- Lf. scaphoid
F2	- Rt. trapezium
F3	- Lf. trapezium
F4	- Rt. Trapezoid
F5	- Lf. trapezoid
F6	- Rt. capitate
F7	- Lf. capitate
F8	- Rt. hamate
F9	- Lf. hamate
G0	- Rt. pisiform
G1	- Lf. pisiform
G2	- Rt. triquetral
G3	- Lf. triquetral
G4	- Rt. lunate
G5	- Lf. lunate
G6	- Rt. metacarpal
G7	- Lf. metacarpal
G8	- Rt. metacarpal
G9	- Lf. metacarpal
H0	- Rt. metacarpel III
H1	- Lf. metacarpal III
H2	- Rt. metacarpal IV
H3	- Lf. metacarpal IV
H4	- Rt. metacarpal V
H5	- Lf. metacarpal V
H6	- Rt. prox. phalanx I
H7	- Lf. prox. phalanx I
H8	- Rt. prox. phalanx II
H9	- Lf. prox. phalanx II
I0	- Rt. prox. phalanx III
I1	- Lf. prox. phalanx III
I2	- Rt. prox. phalanx IV
I3	- Lf. prox. phalanx IV
I4	- Rt. prox. phalanx V
I5	- Lf. prox. phalanx V
I6	- Rt. mid. phalanx II
I7	- Lf. mid. phalanx II
I8	- Rt. mid. phalanx III
I9	- Lf. mid. phalanx III
J0	- Rt. mid. phalanx IV
J1	- Lf. mid. phalanx IV
J2	- Rt. mid. phalanx V
J3	- Lf. mid. phalanx V
J4	- Rt. distal phalanx II
J5	- Lf. distal phalanx II
J6	- Rt. distal phalanx III

TABLE 1. (Cont.)

J7	Lf. distal phalanx III
J8	Rt. distal phalanx IV
J9	Lf. distal phalanx IV
K0	Rt. distal phalanx V
K1	Lf. distal phalanx V
K2	Rt. distal phalanx I
K3	Lf. distal phalanx I
K4	Rt. femur
K5	Lf. femur
K6	Rt. tibia
K7	Lf. tibia
K8	Rt. fibula
K9	Lf. fibula
L0	Rt. calcaneus
L1	Lf. calcaneus
L2	Rt. talus
L3	Lf. talus
L4	Rt. navicular
L5	Lf. navicular
L6	Rt. cuboid
L7	Lf. cuboid
L8	Rt. metatarsal V
L9	Lf. metatarsal V
M0	Rt. medial cuneiform
M1	Lf. medial cuneiform
M2	Rt. int. cureiform
M3	Lf. int. cuneiform
M4	Rt. lat. cuneiform
M5	Lf. lat. cuneiform
M6	Rt. metatarsal I
M7	Lf. metatarsal I
M8	Rt. metatarsal II
M9	Lf. metatarsal II
N0	Rt. metatarsal III
N1	Lf. metatarsal III
N2	Rt. metatarsal IV
N3	Lf. metatarsal IV
N4	Rt. prox. phalanx I
N5	Lf. prox. phalanx I
N6	Rt. prox. phalanx II
N7	Lf. prox. phalanx II
N8	Rt. prox. phalanx III
N9	Lf. prox. phalanx III
O0	Rt. prox. phalanx IV
O1	Lf. prox. phalanx IV
O2	Rt. prox. phalanx V
O3	Lf. prox. phalanx V
O4	Rt. dist. phalanx I
O5	Lf. dist. phalanx I
O6	Rt. mid. phalanx II
O7	Lf. mid. phalanx II
O8	Rt. mid. phalanx III
O9	Lf. mid. phalanx III
P0	Rt. mid. phalanx IV
P1	Lf. mid. phalanx IV
P2	Rt. mid. phalanx V
P3	Lf. mid. phalanx V
P4	Rt. dist. phalanx II
P5	Lf. dist. phalanx II
P6	Rt. dist. phalanx III
P7	Lf. dist. phalanx III
P8	Rt. dist. phalanx IV
P9	Lf. dist. phalanx IV
Q0	Rt. dist. phalanx V
Q1	Lf. dist. phalanx V
Q2	Thoracic vertebra 1
Q3	Thoracic vertebra 2
Q4	Thoracic vertebra 3
Q5	Thoracic vertebra 4
Q6	Thoracic vertebra 5
Q7	Thoracic vertebra 6
Q8	Thoracic vertebra 7
Q9	Thoracic vertebra 8
R0	Thoracic vertebra 9
R1	Thoracic vertebra 10
R2	Thoracic vertebra 11
R3	Thoracic vertebra 12
R4	Lumbar vertebra 1
R5	Lumbar vertebra 2
R6	Lumbar vertebra 3
R7	Lumbar vertebra 4
R8	Lumbar vertebra 5
R9	Sacrum
S0	Coccyx
S1	Rt. 3rd molar, upper
S2	Rt. 2nd molar, upper
S3	Rt. 1st molar, upper
S4	Rt. 2nd premolar, upper
S5	Rt. 1st premolar, upper
S6	Rt. canine, upper
S7	Rt. 2nd incisor, upper
S8	Rt. 1st incisor, upper
S9	Lf. 1st incisor, upper
T0	Lf. 2nd incisor, upper
T1	Lf. canine, upper
T2	Lf. 1st premolar, upper
T3	Lf. 2nd premolar, upper
T4	Lf. 1st molar, upper
T5	Lf. 2nd molar, upper
T6	Lf. 3rd molar, upper
T7	Rt. 3rd molar, lower
T8	Rt. 2nd molar, lower
T9	Rt. 1st molar, lower
V0	Rt. 2nd premolar, lower
V1	Rt. 1st premolar, lower
V2	Rt. canine, lower
V3	Rt. 2nd incisor, lower
V4	Rt. 1st incisor, lower
V5	Lf. 1st incisor, lower
V6	Lf. 2nd incisor, lower
V7	Lf. canine, lower
V8	Lf. 1st premolar, lower
V9	Lf. 2nd premolar, lower
W0	Lf. 1st molar, lower
W1	Lf. 2nd molar, lower
W2	Lf. 3rd molar, lower
W3	Hyoid

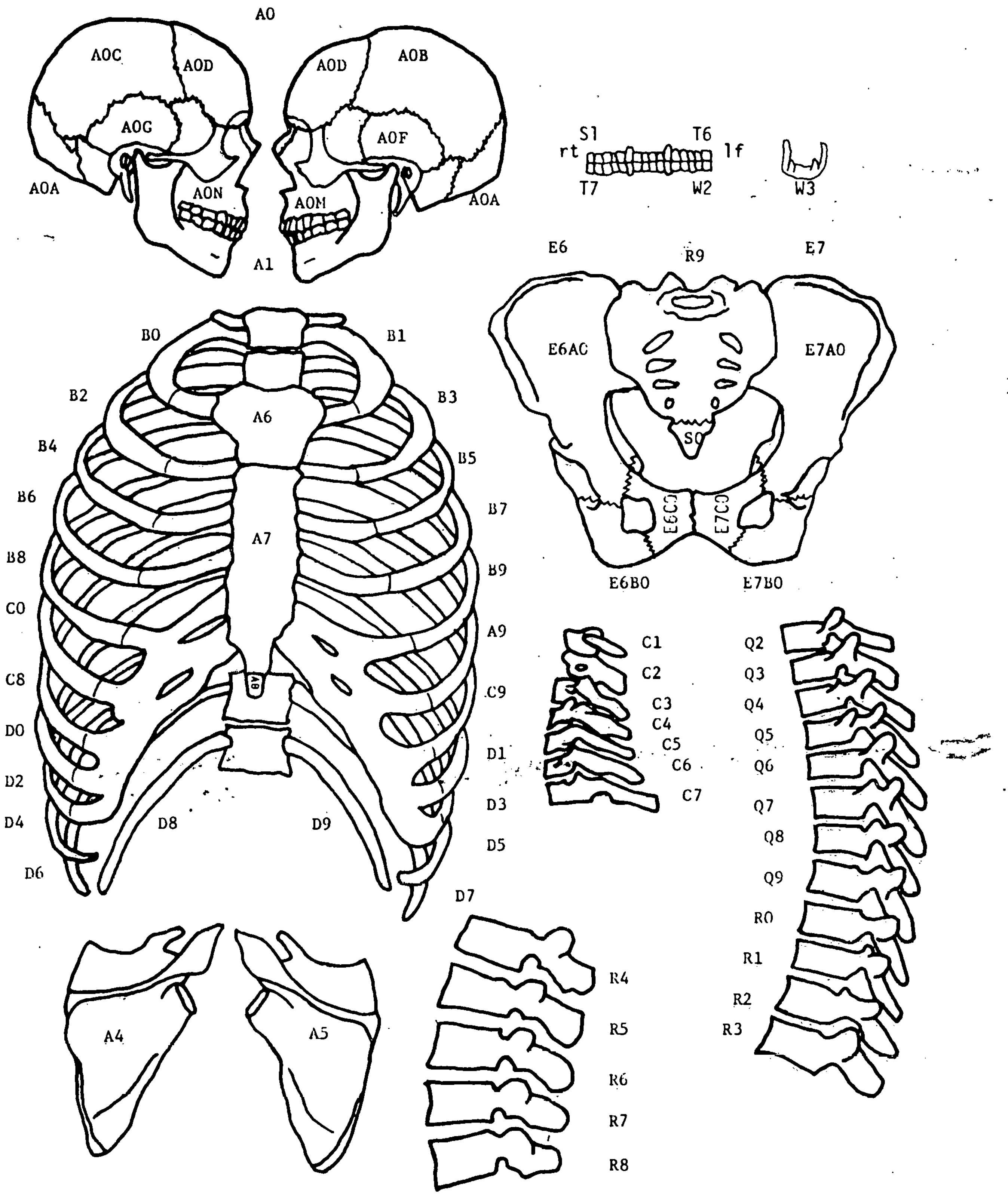

FIG. 1.--Code numbers for whole bones of the axial skeleton, the scapulae, and the pelvis.

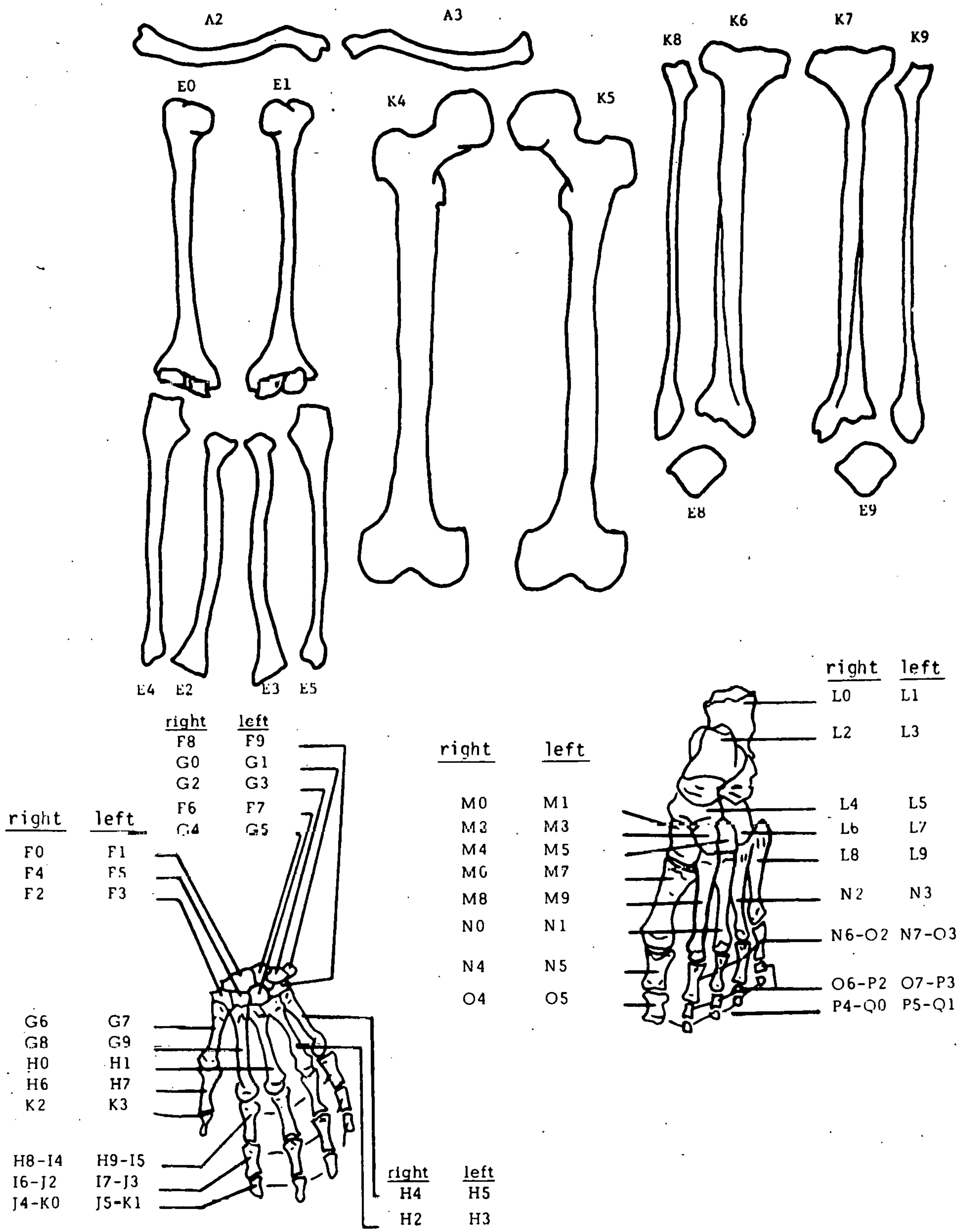

FIG. 2.--Code numbers for whole bones of the appendicular skeleton excluding the scapulae and the pelvis.

innominates minus the crests.

Subdivision of the Long Bones, Clavicles, Ribs, and Vertebrae

We conceptually divide the long bones, clavicles, and ribs into five parts of equal length. An individual code is assigned to any of these parts which is cut from the bone and used experimentally. The codes are obtained by appending A0, B0, D0, or E0 to the codes for the whole bones. A0 denotes the most proximal segment, B0 denotes the adjacent segment and so on. As an example, the codes for the parts of the right femur, K4, are K4A0, K4B0, K4D0, and K4E0. The suffixes F0 and G0 denote the ends of the long bones and its shaft, respectively. Thus, for the right femur, K4F0 denotes the grouping K4A0, K4E0. K4G0 denotes the grouping K4B0, K4C0, K4D0.

The vertebrae are thought of as consisting of two parts. However, two types of subdivision are considered: division into right and left halves, or into processes and body. For example, Q8A0 is assigned to the right half of the 7th thoracic vertebra, Q8B0 is the left half. Q8C0 is the body and Q8D0 are the processes. Figure 3 illustrates these subdivisions using the right femur and the 7th thoracic vertebra as examples.

Bone Segments

All bone segments which are used experimentally are assigned specific codes. The code is arrived at by replacing the rightmost 0 of the whole bone code or a bone subdivision code with a digit between 1 and 9. Thus, segments cut from the most proximal 1/5 of the right femur (K4A0) would be numbered K4A1, K4A2,...., K4A9.

Bone, Teeth, Tissue, and Soil Groupings

Codes have been assigned to groupings of bone, teeth, tissue, and soil which have been used regularly in gamma-ray radioactivity measurements. A listing of these special codes can be found in Table 2.

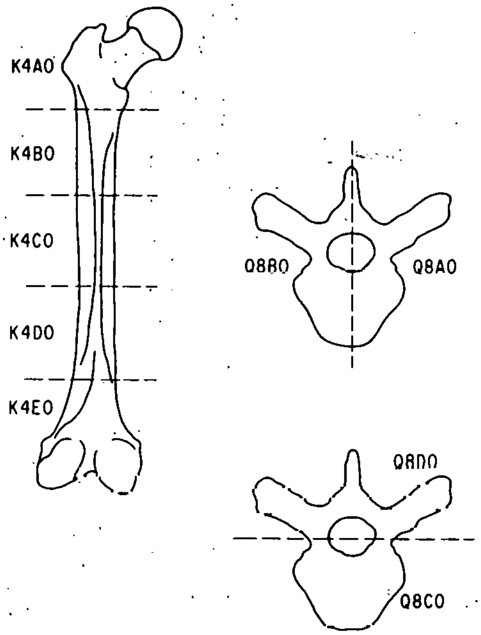

FIG. 3.--Subdivisions of the long bones, clavicles, ribs, and vertebrae illustrated by the right femur and 7th thoracid vertebra.

TABLE 2. Codes for bone, teeth, tissue and soil groupings.

BY	Cremains
W4	Cervical vertebrae, all available bones
W5	Thoracic vertebrae, all Available bones
W6	Lumbar vertebrae, all available bones
W7	Ribs, left, all available bones
W8	Ribs, right all available bones
W9	Ribs, left and right, all available bones
X1	Hand, l., all available bones
X2	Hands, r., all available bones
X3	Hands, both, all available bones
X4	Foot, r., all available bones
X5	Foot, l., all available bones
X6	Feet, both, all available bones
X7	Innominates, less crests
X8	Innominates, crests only
X9	Patellae, both
Y0	Ends of long bones, one side
Y1	Shafts of long bones, one side
Y2	Teeth, all available
Y3	Misc. bones
Y4	Misc. fragments
Y5	Total available skeleton
Y6	Soft tissue
Y7	Periosteal tissue
Y8	Soil.
Y9	Clavicles
Z0	Scapulae

Reference

1. J.E.Farnham and K. A. Rybicki, The preparation of skeletal remains, Argonne National Laboratory Radiological and Environmental Research Division Annual Report, July 1971–June 1972, ANL-7960, Part II, pp. 206–211.

APPENDIX A. Exposure Data for Radium Patients

Table 1 summarizes exposure data collected as of 31 December 1975 for 1832 radium cases under study at the Center for Human Radiobiology. It includes all persons measured for radium since the start of the Center in 1969 and all persons for whom we have analysis data from earlier work at the Radioactivity Center of the Massachusetts Institute of Technology, the New Jersey Radium Research Project of the New Jersey Department of Health, and the Argonne Radium Studies at the Argonne National Laboratory and the Argonne Cancer Research Hospital.

The corresponding table in the 1975 annual report[1] listed 1740 cases, including one unmeasured case (11-099) that was inadvertently listed. The radium burdens of 86 living persons and 4 exhumed remains were measured for the first time in 1975. Three cases not previously listed have been added because reports of measurements made in 1960 were located. The 93 new cases are identified by a star following the year of measurement. There were follow-up examinations and burden measurements in 1975 on 69 previously listed persons. Changes in basic data for several of the previously listed cases are due to review of information on exposure histories and to reassessment of old measurement data.

The cases are listed in order of identification number. In column 5, the type of exposure to radium (dial painting, medical, etc.) is indicated by code digits, which are defined in Table A1; if more than one type of exposure occurred, two non-zero digits are given with the more significant exposure indicated by the right-hand digit. The eight cases previously assigned to exposure type 9 (industrial; filled light pulls) have been reassigned to code 1 (industrial; painted dials), and exposure type code 9 has been discontinued. Column 7 gives the total period (in weeks) from first to last exposure. A value of 0 means that the exposure was a single event or had a duration of less than one week. However, "+0" means that the duration of exposure is unknown (a single exposure or longer); in these cases, zero duration was used in the calculation of the dose. For a dial painter whose first exposure was before the year 1926 but whose period of exposure extended into 1926 or beyond, the duration used in calculating the dose corresponded to the exposure terminating in 1926.

The ^{226}Ra body burdens given in the table are expressed as nanocuries (nCi) of ^{226}Ra present in the year of measurement shown in the preceding column. If several measurements over a period of years had been made for a given case, the result (and data) of the last measurement of highest available quality is given. Under "METHOD + ERR," the first symbol indicates the type of measurement according to the letter code of Table A2. Type A indicates that a complete skeletal measurement of bones was made, the letters B, C, ..., G tend to imply increasingly uncertain types of measurement but with wide variation in size of error within each category. The digit that follows the method letter is the code symbol for an error estimated on the basis of type of measurement, amount of radium found, and examination of the data reported by the contributing laboratories. Code definitions for size of error are given in Table A3, and the errors shown include systematic errors as well as replication errors.

The letter L in place of a digit in the error column indicates that the result was taken from the New Jersey Radium Research Project records in which the measured value of ^{226}Ra was less than 4 nCi, their reported lower limit of detection. For these cases, the value 4 is shown in the ^{226}Ra column, but the letter L means that the 90% confidence limits extend from 0.0 nCi to an upper limit somewhere between 4 and 8 nCi. There are 56 of these cases which have the prefix 05 in the case number and one with case number 01-222. A "less than" indication was not used for cases measured at the other sites, even though the best measurements of small whole-body burdens have a standard deviation of 1–2 nCi. Instead, the measured values are given in the table when the result was zero or positive, and negative results are shown as zeros. These limitations should be kept in mind when evaluating error limits for very small body burdens.

The entries in column 11 are activity ratios of ^{228}Ra to ^{226}Ra at the time of measurement of ^{226}Ra body content. A value of 5.7 yr for the half-life of ^{228}Ra was used in making corrections for radioactive decay. The method and error designations in column 12 are defined in Tables A2 and A3. The letter

TABLE A1. Type of Exposure to ^{226}Ra or ^{228}Ra or Both for TABLE 1

Code Number	Exposure to radium
1	Industrial; painted dials
2	Medical; drank Radithor nostrum
4	Medical; ingestion
5	Medical; injection
6	Laboratory; industry or research
7	Industrial; miscellaneous work or accidents
8	Offspring of a radium case

TABLE A2. Principal Types of Measurement of Body Burdens of ^{226}Ra and ^{228}Ra for TABLE 1

Code letter	Method	Subject or tissue
A	Gamma-ray	Major portions of skeletons or cremation ash
B	Whole-body gamma-ray and breath radon (thoron) with spirometer	In vivo
C	Whole-body gamma-ray	In vivo
D	Breath radon (thoron) with spirometer	In vivo
E	Whole-body gamma-ray (secondary method), alone or with a flask sample of breath radon	In vivo
F	Radiochemical or direct gamma-ray	Bone samples
G	Breath radon with flask	In vivo
Z	Ratio of ^{228}Ra to ^{226}Ra estimated from results on colleagues and/or measurements of radium materials	. . . .

TABLE A3. Error Ranges for ^{226}Ra Body Burdens and $^{228}Ra/^{226}Ra$ Ratios in TABLE 1

Code number	Standard error[(a)]
1	≤ 10%
2	11–20%
3	21–50%
4	1.5 (×, ÷)
5	2 (×, ÷)
6	> 50%
7	3 (×, ÷)
8	Probably an upper limit[(2)]
9	Initial ratio of ^{228}Ra to ^{226}Ra probably ≤ 0.20[(2)]
L	90% confidence limits extend from 0.0 nCi to an upper limit between 4 and 8 nCi

[(a)] Either the relative standard error (given in %) or the factor (×, ÷) corresponding to one standard error in a log normal distribution. For the latter case, the upper and lower limits associated with one standard error are respectively obtained by multiplying and dividing the value in TABLE 1 by the factor; and the square of this factor is used to obtain the corresponding limits for two standard errors.

Z for method means that the ratio for the indicated person was estimated from values obtained on a group of persons with similar exposure histories or from analysis of samples of the radium material to which the person was exposed.[2] If no direct measurement of ^{228}Ra was attempted, only the letter Z and the error designation are shown. If measurement of ^{228}Ra was attempted, the method tried is indicated by the letter after the error symbol in column 12. Ratios obtained by measurements of ^{228}Ra and ^{226}Ra are indicated by a letter other than Z. In all cases, the error designations in column 12 refer to the ratios in column 11. Errors for ratios with method codes of Z or F do not include errors in the measured values of ^{226}Ra body content.

The last four columns of Table 1 give quantities calculated from the measured body burdens and exposure data shown in the other columns. For many cases, the number of significant digits shown obviously exceeds the number justified by the accuracy of the basic data, and the errors indicated for the latter should be applied to the derived quantities. The columns under "INPUT" give the amounts of initially acquired ^{226}Ra and ^{228}Ra expressed as nanocuries per gram of bone (nCi/g), a quantity[3] calculated by applying the Norris retention function[4] to values of body burdens usually measured long after the initial intake. The cumulative rads, given in the last two columns for ^{226}Ra and ^{228}Ra separately, refer to the average ionization dose to the skeleton[5]—either up to the date of death or, for the living subjects, through 1975. Except for the foetal skeleton (case 01-579), the results in the last four columns were calculated with standard skeletal masses of 5 kg for women and 7 kg for men.

References

1. Exposure data for radium patients, Radiological and Environmental Research Division Annual Report, July 1974—June 1975, ANL-75-60, Part II, pp. 152—206.
2. A. T. Keane, A survey of MsTh/Ra ratios, Annual Progress Report, Radioactivity Center, Massachusetts Institute of Technology Report, MIT-952-3, pp. 13—22 (1966).
3. A. F. Stehney, A time-invariant dose parameter for radium cases, Radiological Physics Division Annual Report, July 1970—June 1971, ANL-7860, Part II, pp. 9—15.

4. 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).
5. W. R. Neal, Dose variables and their calculation, Annual Progress Report, Radioactivity Center, Massachusetts Institute of Technology Report, MIT-952-3, pp. 94–141 (May 1966).

TABLE 1 EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
00-001	M	1883	1928	06	1913	780	1967	13000	F4	0.00700	F3	145.10	185.36	2893	8286
00-002	F	1896	1922	01	1917	223	1966	16000	F4	0.00110	F3	199.27	62.05	2313	1369
00-003	F	1894	1927	01	1917	104	1966	7000	F4	0.01200	F1	174.43	714.01	4074	40367
00-004	F	1900	1931	01	1917	88	1963	9000	F4	0.00080	F1	273.49	52.90	8050	3481
00-005	F	1901	1939	01	1917	300	1963	1400	F4	0.00700	Z7	51.54	66.29	1913	4731
00-006	F	1903	1930	01	1918	128	1969	2610	A1	0.00536	A1	71.39	161.56	1859	9901
00-007	F	1903	1935	01	1919	104	1963	1000	F4	0.01000	Z7	32.53	60.48	1038	4124
00-008	M	1890	1938	06	1915	598	1972	3045	A1	0.00288	A3	74.99	97.41	2601	6775
00-009	F	1900	1928	01	1921	234	1969	2650	A1	0.00490	A2	45.93	56.58	728	2035
00-017	F	1899	1924	01	1917	156	1970	17000	A1	0.00069	Z7A	325.15	116.02	5650	4765
00-020	M	1888	1925	06	1912	676	1969	920	A1	0.00228	A6	9.53	6.94	174	286
00-022	F	1889	1925	01	1917	377	1960	10000	F4	0.01000	F1	150.41	161.31	2223	5201
00-027	F	1902	1942	01	1918	130	1970	2500	A1	0.00023	F3	101.02	11.07	4187	808
00-028	F	1902	1933	01	1917	279	1969	10000	F4	0.00036	F1	304.35	42.81	9016	2816
00-029	F	1900		01	1917	409	1969	17	G6	0.0	Z9	1.01	.00	73	0
00-033	M	1868	1922	06	1919	156	1970	6	A6	0.00300	Z7A	.03	.03	0	0
01-001	F	1878	1949	05	1922	+0	1972	15400	A1	0.0	Z9A	680.55	.00	31456	0
01-002	F	1906	1939	01	1922	676	1936	18000	B2	0.02150	F1	519.84	47.28	16586	3220
01-003	M	1888	1956	05	1925	304	1967	12800	A1	0.00037	A3	411.75	17.17	19507	1273
01-004	F	1869	1953	04	1918	+0	1941	10500	E4	0.0	Z9	426.89	.00	23320	0
01-005	M	1877	1939	02	1927	12	1939	5000	E4	0.50000	E4	103.00	218.50	2850	13918
01-006	F	1899	1938	01	1919	260	1970	3590	A1	0.00144	A3	122.43	62.73	4144	4361
01-007	F	1886	1949	05	1926	+0	1967	3620	A1	0.0	Z9A	147.18	.00	6142	0
01-008	F	1900	1958	01	1917	78	1960	6000	F2	0.00067	F3	326.32	37.18	19519	2790
01-009	F	1898	1945	01	1918	52	1960	6500	F4	0.00050	F2	284.45	22.10	12991	1634
01-010	M	1882	1956	04	1926	+0	1967	5200	A1	0.0	Z9A	173.38	.00	8574	0
01-011	F	1872	1937	04	1919	156	1967	4650	A1	0.0	Z9A	158.89	.00	5380	0
01-012	F	1867	1956	05	1922	+0	1970	5800	A1	0.0	Z9A	288.95	.00	15491	0
01-014	F	1901	1949	01	1916	156	1968	2240	A1	0.00036	F3	107.22	17.80	5471	1328
01-015	M	1888	1967	01	1917	780	1935	200	E4	0.0	Z9	4.34	.00	281	0
01-016	F	1891	1966	01	1921	208	1973	1940	A1	0.00245	F2	109.17	115.55	6817	8678
01-017	F	1883		02	1926	156	1971	1210	B1	0.00322	B2	68.51	43.46	4566	3266
01-018	M	1889	1958	06	1911	2340	1950	1250	B2	0.0	Z9B	26.46	.00	1110	0
01-019	F	1903	1936	01	1922	253	1965	240	A1	0.02958	A2	6.93	29.50	193	1879
01-020	F	1905	1956	05	1923	5	1950	1500	E4	0.0	Z9	66.23	.00	3479	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
01-021	F	1887	1973	01	1916	104	1965	1250	E4	0.00040	Z7	74.50	10.18	5531	766
01-022	F	1900	1951	01	1917	110	1968	600	A2	0.0	Z9A	29.40	.00	1544	0
01-024	F	1901	1956	01	1919	156	1943	1140	B2	0.02190	F3	45.79	15.35	2525	1149
01-025	F	1886	1952	05	1924	+0	1951	1200	B2	0.00250	F3	53.03	3.54	2509	262
01-026	F	1905	1958	01	1925	156	1950	700	B2	0.03000	D5	29.41	17.34	1531	1295
01-027	M	1889	1957	06	1912	1040	1960	500	A2	0.0	Z9F	17.86	.00	973	0
01-028	M	1879	1965	06	1912	260	1953	250	E4	0.0	Z9	9.49	.00	658	0
01-029	M	1876	1958	06	1902	+0	1950	300	G4	0.0	Z9	12.77	.00	948	0
01-030	M	1882	1952	07	1936	0	1950	20	F4	0.0	Z9	.45	.00	15	0
01-031	F	1906	1934	01	1925	4	1963	734	A1	0.05653	A1	18.28	104.49	426	5904
01-032	F	1908	1940	01	1924	201	1968	1450	A1	0.02800	A1	47.17	245.54	1506	16742
01-033	F	1908	1931	01	1923	42	1963	2472	A1	0.05153	A1	56.47	358.65	1192	18509
01-034	F	1913		01	1929	18	1965	8	G6	0.01000	Z8	.41	.32	27	24
01-035	F	1901	1972	01	1920	19	1971	0	B6	0.01860	Z2B	.00	.00	0	0
01-037	F	1908		01	1928	26	1974	0	B6	0.00327	Z8B	.00	.00	0	0
01-038	F	1910		01	1927	111	1959	8	B2	0.02000	Z8B	.38	.33	25	24
01-039	F	1915		07	1934	1092	1972	1	B6	0.0	Z9B	.04	.00	2	0
01-040	F	1907	1929	01	1923	60	1963	4300	A1	0.05209	A1	82.35	517.03	1422	21160
01-041	F	1909		01	1927	22	1971	0	B6	0.00470	Z8B	.00	.00	0	0
01-043	F	1912		01	1927	8	1958	9	B6	0.02200	Z8B	.43	.40	29	30
01-044	F	1904		01	1924	22	1959	4	B3	0.08000	Z2B	.20	1.11	14	83
01-045	F	1889		01	1922	237	1959	0	B6	0.08000	Z2B	.00	.00	0	0
01-046	F	1903	1943	01	1920	657	1963	551	A1	0.05607	A1	20.77	146.20	793	10502
01-047	F	1896		01	1920	367	1962	80	G4	0.05700	Z2	4.28	27.23	302	2047
01-048	F	1900		01	1920	206	1957	140	B2	0.09290	F2	7.08	45.95	507	3455
01-049	F	1903	1937	01	1920	1	1960	1000	A1	0.07300	A2	34.73	328.13	1198	22993
01-050	F	1911		01	1925	10	1973	3	B6	0.00370	Z8B	.18	.22	12	17
01-051	F	1904		01	1923	162	1957	150	B2	0.13330	D5	7.30	50.28	506	3780
01-052	F	1910	1930	01	1924	144	1965	2000	A1	0.03500	A1	36.58	164.76	602	6301
01-054	F	1909	1937	01	1924	202	1965	2100	A1	0.03714	A1	60.82	291.42	1692	18610
01-055	F	1907		01	1925	85	1973	4	B3	0.01470	Z2B	.24	1.12	16	84
01-056	F	1904		01	1920	364	1965	134	B1	0.03432	B2	7.45	41.12	527	3092
01-057	F	1908	1931	01	1924	81	1963	4900	A1	0.05163	A1	100.72	540.80	1887	24482
01-059	F	1905	1967	01	1920	299	1964	180	B1	0.04277	B2	9.89	61.34	628	4608
01-060	F	1909		07	1928	20	1974	0	B6	0.01300	Z2B	.00	.00	0	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
01-063	F	1912		01	1927	213	1972	46	B2	0.00250	Z8B	2.59	1.19	169	89
01-066	F	1904		01	1925	0	1975	0	B6	0.00290	Z8B	.00	.00	0	0
01-069	F	1905		01	1922	82	1973	2	B6	0.01470	Z2B	.12	.80	9	60
01-070	F	1910		01	1927	63	1973	1	B6	0.00370	Z8B	.06	.05	4	4
01-071	F	1908	1967	01	1927	6	1958	0	B6	0.0	Z9B	.00	.00	0	0
01-072	F	1899		01	1921	130	1954	100	E4	0.10000	D5	4.81	22.73	343	1709
01-073	F	1900	1969	01	1921	122	1966	87	B1	0.03563	B2	4.95	36.21	327	2722
01-074	F	1909		01	1927	47	1971	7	B3	0.00450	Z8B	.40	.36	26	27
01-075	F	1902		01	1922	52	1973	5	B3	0.01470	Z2B	.31	2.09	22	157
01-078	F	1909		01	1925	40	1974	4	B6	0.00313	Z8B	.24	.28	16	21
01-079	F	1901	1943	01	1920	176	1960	750	F4	0.09070	F1	29.28	277.33	1164	20106
01-080	F	1902		01	1921	204	1968	106	B1	0.02075	B3	6.11	29.98	432	2254
01-081	F	1907		01	1923	11	1959	7	B6	0.08000	Z2B	.36	2.26	25	170
01-082	F	1902	1935	01	1919	230	1953	1030	A1	0.03786	A1	31.98	191.24	968	12727
01-084	F	1904		01	1923	712	1974	46	B2	0.01297	Z2B	2.79	14.76	193	1110
01-085	F	1913		01	1927	47	1958	6	B6	0.02200	Z8B	.28	.26	19	19
01-086	F	1907	1966	01	1925	4	1959	0	B6	0.08000	Z2B	.00	.00	0	0
01-087	F	1905		01	1921	344	1954	780	F4	0.03690	F1	42.54	212.14	2989	15952
01-090	F	1910		01	1927	90	1974	6	B3	0.00313	Z8B	.35	.30	23	22
01-091	F	1907		01	1927	264	1974	0	B6	0.00327	Z8E	.00	.00	0	0
01-092	F	1906		01	1922	24	1971	2	B6	0.01860	Z2E	.12	.84	9	63
01-093	F	1904		01	1926	8	1971	0	B6	0.0	Z9E	.00	.00	0	0
01-094	F	1888	1966	01	1921	128	1964	11	G4	0.04400	Z2	.61	4.29	39	322
01-095	F	1907		01	1922	34	1975	6	B2	0.01163	Z2E	.38	2.64	27	198
01-096	F	1909		01	1927	310	1960	27	D2	0.01800	Z8	1.26	.85	81	64
01-097	F	1905		01	1921	110	1963	122	B1	0.03852	B2	6.69	37.34	479	2808
01-099	F	1905	1945	01	1924	18	1963	164	A1	0.05365	A2	6.33	38.16	248	2760
01-100	F	1905	1967	01	1924	36	1957	34	B2	0.13200	D5	1.66	11.61	103	872
01-101	F	1905		01	1924	4	1959	0	B6	0.08000	Z2B	.00	.00	0	0
01-105	F	1898	1945	01	1921	21	1963	460	A1	0.05217	A1	19.04	160.10	812	11743
01-106	F	1902		01	1924	155	1959	10	B2	0.08000	Z2B	.50	2.48	34	187
01-110	F	1909		01	1925	93	1974	3	B6	0.00313	Z8B	.18	.21	12	15
01-111	F	1910		01	1927	16	1974	2	B6	0.00313	Z8B	.12	.11	8	8
01-112	F	1908	1955	01	1924	835	1960	80	F4	0.07000	F1	3.73	18.38	185	1368
01-113	F	1912		01	1928	5	1959	3	B6	0.02000	Z8B	.14	.12	9	9

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
01-115	F	1908	1944	01	1924	330	1963	472	A1	0.03093	A1	17.37	54.38	642	3883
01-116	F	1899	1965	01	1920	459	1955	290	G4	0.10000	G5	13.98	66.60	860	5000
01-118	F	1909	1971	01	1923	13	1959	0	B6	0.08000	Z2B	.00	.00	0	0
01-119	F	1899	1966	01	1920	14	1958	5	B6	0.09000	Z2B	.26	2.37	17	178
01-120	F	1910		01	1925	125	1959	10	B2	0.02000	Z8B	.49	.58	34	44
01-122	F	1912		01	1927	49	1975	11	B2	0.0	Z9B	.65	.00	43	0
01-123	F	1889		01	1923	11	1973	0	B6	0.01470	Z2B	.00	.00	0	0
01-124	F	1909		01	1927	64	1973	55	B2	0.00370	Z8B	3.18	2.93	212	221
01-125	F	1911		01	1927	5	1974	0	B6	0.00327	Z8B	.00	.00	0	0
01-126	F	1903	1969	01	1922	416	1969	150	A1	0.03133	A3	8.64	63.70	556	4786
01-127	F	1908		01	1927	9	1974	1	B6	0.00330	Z8B	.06	.06	4	4
01-128	F	1910		01	1927	4	1959	2	B6	0.02000	Z8B	.10	.09	6	7
01-130	F	1909		01	1926	196	1964	11	B2	0.01140	Z8B	.57	.52	37	39
01-132	F	1908	1944	01	1923	76	1966	1327	A1	0.03496	A1	50.51	300.94	1946	21690
01-133	F	1910		01	1926	65	1958	13	B2	0.03000	Z8B	.62	.84	42	64
01-136	F	1907		01	1923	185	1967	67	B1	0.02537	B3	3.75	16.59	260	1247
01-137	F	1901		01	1923	714	1974	4	B3	0.01295	Z2B	.24	1.28	17	96
01-138	F	1883	1963	04	1919	4	1959	10	G6	0.0	Z9	.54	.00	34	0
01-139	M	1881	1964	02	1928	130	1962	1270	B1	0.01417	B2	44.31	33.53	2409	2509
01-140	F	1890		01	1919	78	1975	0	B6	0.0	Z9B	.00	.00	0	0
01-141	M	1886		02	1928	130	1974	17	B2	0.00330	Z5B	.70	.53	45	40
01-142	F	1899		01	1917	52	1969	0	G6	0.0	Z9	.00	.00	0	0
01-143	F	1904		01	1921	52	1973	3	B6	0.0	Z9B	.19	.00	13	0
01-144	F	1897	1973	04	1922	26	1971	694	B1	0.0	Z9B	41.70	.00	2902	0
01-145	F	1900	1957	01	1918	60	1966	6331	A1	0.00077	A3	336.11	82.61	19506	6195
01-146	F	1882	1967	02	1927	156	1968	100	A1	0.00870	Z5A	5.31	5.60	309	420
01-147	F	1902		01	1917	26	1965	52	G4	0.0	Z9	3.09	.00	234	0
01-148	F	1907		06	1936	364	1958	40	G4	0.0	Z9	1.45	.00	80	0
01-149	F	1888	1959	01	1919	26	1969	1630	A1	0.00533	A3	88.08	199.03	5226	14933
01-150	F	1881		04	1930	104	1970	3	B6	0.0	Z9B	.16	.00	10	0
01-151	F	1905		06	1927	52	1970	0	G6	0.0	Z9	.00	.00	0	0
01-152	F	1904		01	1920	17	1972	0	B2	0.00290	Z5B	.00	.00	0	0
01-153	M	1890	1964	06	1920	104	1963	280	B1	0.0	Z9B	11.12	.00	694	0
01-154	M	1896	1968	06	1923	40	1959	0	G6	0.0	Z9	.00	.00	0	0
01-156	F	1900	1959	01	1918	156	1959	40	G6	0.0	Z9	2.15	.00	127	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
01-157	F	1894		02	1925	13	1975	49	B2	0.00139	Z5B	2.98	1.79	205	134
01-158	F	1901		06	1920	52	1959	1	G6	0.0	Z9	.05	.00	4	0
01-159	F	1915		01	1933	312	1972	2	B6	0.0	Z9B	.10	.00	6	0
01-160	F	1873	1965	02	1925	+0	1959	130	B1	0.02000	B3	6.48	8.09	386	607
01-161	F	1896	1973	01	1918	17	1959	1	B6	0.0	Z9B	.05	.00	4	0
01-162	M	1898	1966	06	1920	364	1959	95	B1	0.0	Z9B	3.45	.00	214	0
01-163	F	1903		01	1920	26	1972	2	B6	0.00360	Z7B	.12	.24	9	18
01-164	F	1900	1972	01	1918	39	1959	9	B2	0.0	Z9B	.49	.00	35	0
01-165	F	1904		01	1922	22	1974	13	B2	0.0	Z9C	.82	.00	59	0
01-166	F	1897	1969	01	1916	26	1959	0	B6	0.0	Z9B	.00	.00	0	0
01-168	F	1895		06	1919	468	1966	1	B6	0.0	Z9B	.06	.00	4	0
01-169	F	1918		01	1936	69	1975	0	B6	0.0	Z9B	.00	.00	0	0
01-170	M	1893	1966	05	1940	0	1959	4	G6	0.0	Z9	.11	.00	5	0
01-171	M	1895	1975	45	1914	6	1958	1500	B1	0.0	Z9B	60.99	.00	4788	0
01-172	F	1898	1968	01	1916	136	1961	1960	B1	0.00112	B3	111.24	25.16	7736	1892
01-173	M	1881	1959	06	1917	1300	1959	70	G4	0.0	Z9	2.26	.00	110	0
01-175	F	1900	1966	02	1927	13	1965	1710	B1	0.00760	B2	90.11	68.52	5269	5139
01-176	F	1893	1969	01	1917	104	1969	0	G6	0.0	Z9	.00	.00	0	0
01-177	M	1915		06	1936	312	1969	61	B1	0.0	Z9B	2.03	.00	113	0
01-178	M	1939		07	1958	0	1973	2	B6	0.0	Z9C	.04	.00	1	0
01-179	F	1890	1966	45	1924	58	1959	2000	B1	0.0	Z9B	100.31	.00	6115	0
01-180	F	1900		01	1918	26	1971	3	B3	0.0	Z9B	.19	.00	14	0
01-181	M	1913	1963	06	1940	130	1959	220	B1	0.0	Z9B	5.58	.00	225	0
01-182	M	1902	1959	02	1936	+0	1959	7	D3	0.02600	Z5D	.20	.09	8	6
01-183	F	1901	1969	01	1915	78	1969	203	A1	0.0	Z9A	12.77	.00	917	0
01-184	M	1887	1969	05	1922	10	1968	48	B2	0.0	Z9B	2.00	.00	132	0
01-185	M	1881	1962	06	1912	+0	1959	40	G6	0.0	Z9	1.68	.00	116	0
01-186	M	1925		06	1943	416	1972	27	B2	0.0	Z9B	.82	.00	39	0
01-187	M	1917		06	1943	78	1959	42	B2	0.0	Z9B	.98	.00	50	0
01-188	F	1886		04	1933	3	1959	4	G6	0.0	Z9	.17	.00	11	0
01-189	M	1921		07	1958	0	1973	0	B6	0.0	Z9C	.00	.00	0	0
01-190	F	1927		07	1958	0	1973	0	B6	0.0	Z9C	.00	.00	0	0
01-191	M	1897	1966	06	1913	78	1959	4	B6	0.0	Z9B	.17	.00	12	0
01-192	F	1902	1962	01	1925	52	1959	34	B2	0.00100	Z7B	1.68	.10	94	7
01-193	F	1886	1960	06	1917	156	1974	31	A2	0.0	Z9	1.71	.00	105	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
01-194	M	1898		01	1916	676	1972	7	B6	0.0	Z9B	.31	.00	22	0
01-195	F	1893	1958	06	1912	520	1959	1	F6	0.0	Z9	.05	.00	3	0
01-196	M	1907		02	1930	20	1972	69	B1	0.00540	Z5B	2.73	2.38	175	179
01-197	F	1883	1965	04	1916	+0	1958	16	G6	0.0	Z9	.89	.00	61	0
01-200	F	1910		01	1925	220	1959	0	B6	0.08000	Z2B	.00	.00	0	0
01-201	F	1911		01	1925	55	1959	26	B2	0.02100	Z8B	1.29	1.59	88	119
01-203	F	1908		01	1923	1	1973	0	B6	0.01470	Z2B	.00	.00	0	0
01-204	F	1901		01	1917	22	1959	5	B3	0.0	Z9B	.28	.00	21	0
01-205	M	1921	1974	06	1951	52	1972	7	B3	0.0	Z9C	.20	.00	8	0
01-206	M	1896		06	1918	17	1975	9	B2	0.0	Z9B	.42	.00	31	0
01-207	F	1909	1967	01	1927	9	1959	4	B3	0.02000	Z8B	.19	.19	11	14
01-208	M	1901	1972	06	1939	1144	1971	918	B1	0.0	Z9B	24.42	.00	982	0
01-209	F	1908	1975	01	1926	16	1959	6	B6	0.02700	Z8B	.29	.43	20	32
01-210	M	1878	1971	06	1918	2028	1959	12	B2	0.0	Z9B	.28	.00	15	0
01-214	M	1891	1964	06	1915	1248	1959	82	B1	0.0	Z9B	2.77	.00	156	0
01-216	F	1903	1963	01	1924	4	1959	0	B6	0.08000	Z2B	.00	.00	0	0
01-217	M	1894	1971	01	1914	208	1959	5	B3	0.0	Z9B	.20	.00	15	0
01-218	M	1924		06	1950	780	1974	0	B6	0.0	Z9B	.00	.00	0	0
01-219	F	1910		01	1927	10	1971	1	B6	0.00450	Z8B	.06	.05	4	4
01-220	F	1907		01	1924	26	1959	2	B6	0.07100	Z2B	.10	.49	7	37
01-221	M	1892	1970	06	1916	520	1967	10	B2	0.0	Z9B	.42	.00	28	0
01-222	F	1910		01	1925	17	1964	4	CL	0.04400	Z2C	.21	1.06	15	79
01-223	F	1912		01	1927	7	1963	0	G6	0.01200	Z8	.00	.00	0	0
01-225	F	1906		01	1931	35	1959	0	D6	0.0	Z9D	.00	.00	0	0
01-226	F	1911		01	1927	22	1973	0	B6	0.00370	Z8B	.00	.00	0	0
01-227	F	1908		07	1933	2184	1975	0	B6	0.0	Z9B	.00	.00	0	0
01-228	F	1906		01	1926	61	1972	6	B6	0.00420	Z8B	.35	.36	23	27
01-229	F	1903		01	1923	2	1959	8	B2	0.08000	Z2B	.41	2.61	29	196
01-230	F	1913		01	1927	19	1973	1	B6	0.00370	Z8B	.06	.06	4	4
01-231	F	1910	1969	01	1930	84	1959	0	B6	0.0	Z9B	.00	.00	0	0
01-232	F	1909	1961	04	1926	43	1959	0	B6	0.0	Z9B	.00	.00	0	0
01-233	F	1912	1973	01	1927	145	1959	2	B6	0.02000	Z8B	.09	.08	6	6
01-234	F	1913	1966	01	1927	1	1959	0	B6	0.0	Z9B	.00	.00	0	0
01-235	F	1908		01	1925	8	1959	1	B6	0.08000	Z2B	.05	.25	3	19
01-236	F	1910		01	1927	9	1965	1	G6	0.01000	Z8	.05	.05	4	4

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
01-237	F	1908		01	1927	8	1975	0	B6	0.00290	Z8B	.00	.00	0	0
01-238	F	1896	1967	01	1920	2	1959	1	B6	0.08000	Z2B	.05	.49	4	37
01-239	F	1901	1958	01	1917	78	1957	830	F4	0.00157	F3	44.55	8.26	2665	620
01-240	F	1910		01	1927	13	1971	7	D6	0.00450	Z8D	.40	.37	27	28
01-243	M	1873	1959	06	1905	520	1958	15	G6	0.0	Z9	.64	.00	43	0
01-244	F	1901		01	1927	18	1975	1	B6	0.00307	Z8	.06	.06	4	5
01-245	F	1920		01	1957	30	1969	0	G6	0.0	Z9	.00	.00	0	0
01-246	F	1885	1970	06	1915	39	1967	3	B6	0.0	Z9B	.19	.00	14	0
01-247	M	1901		06	1923	689	1973	7	B3	0.00280	Z7B	.28	.14	18	10
01-248	F	1903		01	1917	208	1973	24	B2	0.0	Z9B	1.52	.00	113	0
01-249	M	1928		08	1928	39	1967	2	G6	0.02700	Z2	.08	.22	5	17
01-250	M	1894		06	1916	520	1971	0	B6	0.0	Z9B	.00	.00	0	0
01-251	M	1890	1965	06	1912	156	1974	11	A2	0.0	Z9	.49	.00	34	0
01-252	F	1898		01	1917	104	1972	28	B2	0.0	Z9B	1.77	.00	133	0
01-253	F	1898	1964	01	1916	104	1959	40	G6	0.0	Z9	2.22	.00	147	0
01-254	F	1910		01	1927	2	1971	1	B6	0.0	Z9B	.06	.00	4	0
01-255	F	1920		01	1942	52	1975	0	B6	0.0	Z9B	.00	.00	0	0
01-256	M	1920		06	1949	208	1959	14	G6	0.0	Z9	.23	.00	10	0
01-257	M	1885	1962	06	1941	624	1959	0	G6	0.0	Z9	.00	.00	0	0
01-258	M	1903		06	1923	1092	1969	17	G6	0.0	Z9	.61	.00	37	0
01-259	F	1910		06	1927	416	1969	9	G6	0.0	Z9	.47	.00	30	0
01-260	F	1891	1960	04	1918	50	1959	15	G6	0.0	Z9	.82	.00	50	0
01-261	F	1909	1969	01	1927	2	1959	0	B6	0.02000	Z8B	.00	.00	0	0
01-262	F	1895		06	1918	0	1969	22	G4	0.0	Z9	1.35	.00	102	0
01-263	F	1897		01	1917	17	1969	9	B2	0.00020	Z7B	.56	.06	42	5
01-264	M	1906	1967	01	1944	770	1964	90	G4	0.0	Z9	1.81	.00	59	0
01-265	F	1902		01	1919	2	1959	3	B6	0.08000	Z2B	.16	1.68	12	126
01-266	F	1904	1961	01	1923	3	1959	1	B6	0.08000	Z2B	.05	.33	3	24
01-267	F	1904		01	1926	104	1966	45	G4	0.0	Z9	2.41	.00	162	0
01-268	F	1901	1968	01	1917	48	1967	100	B2	0.01000	B2	6.06	25.02	421	1882
01-269	M	1911		06	1932	52	1974	0	B6	0.0	Z9B	.00	.00	0	0
01-270	F	1922		01	1943	32	1959	0	G6	0.0	Z9	.00	.00	0	0
01-271	F	1900		01	1917	86	1974	1	B6	0.0	Z9B	.06	.00	5	0
01-272	M	1888		06	1956	130	1959	78	G6	0.0	Z9	.54	.00	19	0
01-273	F	1907		01	1924	1	1959	2	B6	0.08400	Z2B	.10	.60	7	45

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
01-274	F	1906		01	1922	5	1961	5	B3	0.06200	Z2B	.27	1.89	19	142
01-275	M	1930		06	1959	+0	1959	23	G6	0.0	Z9	.00	.00	0	0
01-276	M	1930	1962	06	1945	208	1959	60	G6	0.0	Z9	1.24	.00	39	0
01-277	F	1909		01	1925	6	1962	0	G6	0.05700	Z2	.00	.00	0	0
01-278	F	1904		06	1925	0	1969	10	G6	0.0	Z9	.57	.00	39	0
01-279	M	1901	1969	06	1928	1404	1966	0	G6	0.0	Z9	.00	.00	0	0
01-280	F	1905		01	1926	7	1971	0	B6	0.0	Z9B	.00	.00	0	0
01-282	M	1893	1973	06	1916	156	1972	42	B2	0.0	Z9B	1.91	.00	141	0
01-283	F	1895	1971	07	1918	52	1959	3	B6	0.0	Z9B	.16	.00	12	0
01-284	M	1892	1970	06	1943	780	1959	5	B3	0.0	Z9B	.07	.00	3	0
01-285	F	1900		01	1923	1	1960	4	B6	0.07100	Z2B	.21	1.33	15	100
01-287	F	1908		01	1927	520	1960	7	C6	0.01800	Z8C	.31	.16	20	12
01-288	F	1894	1970	01	1926	2	1960	2	C6	0.02400	Z8C	.10	.15	6	11
01-289	F	1899		01	1919	80	1971	4	B3	0.01860	Z2B	.25	2.32	18	175
01-291	F	1910	1969	01	1928	17	1960	5	B6	0.01800	Z8B	.24	.21	15	16
01-293	F	1911		01	1924	11	1973	0	B6	0.01470	Z2B	.00	.00	0	0
01-294	F	1912		01	1927	52	1971	3	B3	0.00450	Z8B	.17	.15	11	11
01-295	F	1910		01	1927	14	1973	1	B6	0.00370	Z8B	.06	.06	4	4
01-296	F	1908		01	1927	5	1960	0	B6	0.01800	Z8B	.00	.00	0	0
01-297	F	1901		01	1921	122	1960	16	B2	0.09375	B3	.84	7.82	60	588
01-299	F	1896		01	1917	104	1968	3	G6	0.0	Z9	.18	.00	14	0
01-301	F	1904		05	1926	5	1969	17	G4	0.0	Z9	.96	.00	65	0
01-302	F	1899	1966	05	1927	10	1968	2850	A1	0.0	Z9A	152.29	.00	8910	0
01-303	M	1919		01	1940	104	1974	0	B6	0.0	Z9B	.00	.00	0	0
01-305	M	1925	1968	06	1946	1040	1966	160	G4	0.0	Z9C	2.07	.00	56	0
01-306	M	1928		06	1955	364	1973	33	B2	0.0	Z9B	.75	.00	25	0
01-307	M	1930		06	1957	104	1975	4	B6	0.0	Z9B	.10	.00	3	0
01-308	M	1918	1957	06	1943	728	1958	1200	F4	0.0	Z9F	12.92	.00	247	0
01-309	F	1908	1973	01	1923	2	1961	2	B6	0.06200	Z2B	.11	.66	7	50
01-310	F	1928		08	1928	39	1975	0	B6	0.01148	Z2	.00	.00	0	0
01-311	F	1911		01	1927	2	1961	1	B6	0.01500	Z8B	.05	.05	3	3
01-312	F	1907		01	1925	13	1973	2	B6	0.0	Z9B	.12	.00	8	0
01-313	M	1892		06	1911	624	1961	3	B3	0.0	Z9B	.12	.00	9	0
01-314	F	1909		01	1924	0	1961	1	B6	0.06200	Z2B	.05	.29	4	22
01-324	F	1907		01	1923	15	1962	1	G6	0.05700	Z2	.05	.34	4	26

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
01-326	F	1896	1973	02	1925	156	1966	100	G4	0.01100	Z5	5.38	7.17	354	539
01-327	F	1903		01	1927	1	1965	0	G6	0.0	Z9	.00	.00	0	0
01-330	M	1915		06	1942	364	1972	102	B1	0.0	Z9B	3.18	.00	156	0
01-331	M	1901		02	1927	+0	1966	80	G4	0.01100	Z5	3.06	3.86	205	290
01-332	F	1912	1971	01	1927	52	1965	0	G6	0.0	Z9	.00	.00	0	0
01-333	F	1907		01	1924	10	1960	0	G6	0.07400	Z2	.00	.00	0	0
01-335	F	1899		16	1917	78	1975	3	B3	0.0	Z9B	.20	.00	15	0
01-336	M	1899		06	1945	1092	1972	50	B1	0.0	Z9B	1.15	.00	43	0
01-341	M	1883		06	1943	176	1961	5	B3	0.0	Z9B	.12	.00	6	0
01-342	M	1897		06	1944	56	1961	1	B6	0.0	Z9B	.02	.00	1	0
01-343	F	1873	1954	04	1927	+0	1953	0	F6	0.0	Z9	.00	.00	0	0
01-344	F	1904		01	1922	19	1952	7	G6	0.05700	Z2	.38	2.73	27	206
01-345	F	1910		01	1924	1	1962	4	G6	0.05700	Z2	.21	1.22	15	92
01-346	F	1911		01	1927	17	1962	44	G6	0.01700	Z8	2.22	2.61	149	196
01-347	M	1896	1968	06	1926	1872	1962	14	B2	0.0	Z9B	.25	.00	10	0
01-348	F	1902	1973	01	1924	19	1966	112	B1	0.03482	B2	6.21	34.96	422	2628
01-349	F	1907	1967	01	1924	10	1966	93	B1	0.03225	B2	5.17	27.20	322	2043
01-350	F	1898		01	1923	108	1962	0	G6	0.05700	Z2	.00	.00	0	0
01-351	F	1906		01	1923	3	1962	0	G6	0.05700	Z2	.00	.00	0	0
01-352	M	1922		06	1940	338	1962	191	B1	0.0	Z9B	4.97	.00	255	0
01-356	M	1912	1973	06	1937	572	1969	23	B2	0.0	Z9B	.71	.00	36	0
01-357	F	1907	1970	07	1927	408	1962	0	G6	0.0	Z9	.00	.00	0	0
01-358	F	1906		07	1923	168	1962	0	G6	0.05700	Z2	.00	.00	0	0
01-359	F	1908		01	1925	55	1962	25	B2	0.05600	Z2B	1.29	6.12	88	460
01-360	F	1911		01	1928	34	1962	0	G6	0.01400	Z8	.00	.00	0	0
01-361	F	1907		01	1924	20	1974	1	B6	0.01323	Z2B	.06	.34	4	26
01-362	F	1906		01	1923	5	1962	0	G6	0.05700	Z2	.00	.00	0	0
01-363	F	1888		01	1918	260	1962	7	G6	0.05700	Z2	.39	3.36	28	253
01-364	F	1911		07	1927	440	1964	6	G6	0.01140	Z8	.29	.17	18	13
01-365	F	1901		01	1924	40	1962	10	G6	0.05700	Z2	.53	2.90	36	218
01-367	F	1899		01	1920	221	1973	4	B3	0.01470	Z2B	.25	1.73	18	130
01-368	M	1925		06	1947	65	1972	44	B2	0.0	Z9B	1.32	.00	61	0
01-369	F	1906		01	1923	33	1975	0	B6	0.01043	Z2	.00	.00	0	0
01-370	F	1904		01	1927	21	1962	0	G6	0.01500	Z8	.00	.00	0	0
01-371	F	1912		07	1928	36	1962	0	G6	0.01400	Z8	.00	.00	0	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
01-372	F	1911		01	1927	1	1962	7	G6	0.01470	Z8	.35	.37	24	28
01-373	F	1911		01	1927	84	1962	2	G6	0.01000	Z8	.10	.06	7	5
01-374	F	1910		01	1927	+0	1962	12	G6	0.01470	Z8	.61	.63	41	47
01-376	F	1907	1973	01	1927	33	1963	2	G6	0.01300	Z8	.10	.10	7	8
01-377	F	1915		17	1929	208	1975	0	B6	0.0	Z9B	.00	.00	0	0
01-378	F	1907		01	1925	94	1973	1	B6	0.00370	Z8B	.06	.07	4	5
01-379	F	1909		01	1926	7	1975	18	B2	0.00281	Z8B	1.08	1.17	74	88
01-380	F	1910		01	1927	3	1972	0	B6	0.0	Z9B	.00	.00	0	0
01-381	M	1887		02	1927	1	1964	5	G6	0.01400	Z5	.19	.23	12	18
01-382	F	1900		01	1920	320	1963	43	G4	0.01000	Z2	2.33	2.94	165	221
01-383	F	1907		01	1923	2	1972	3	B6	0.01630	Z2B	.18	1.14	13	86
01-384	F	1905		01	1923	1	1975	0	B6	0.01177	Z2	.00	.00	0	0
01-385	F	1906	1971	01	1924	11	1963	5	G6	0.05000	Z2	.27	1.51	18	114
01-386	F	1904		01	1927	15	1963	9	G4	0.01300	Z8	.46	.47	31	35
01-388	F	1873	1944	02	1928	+0	1965	2580	A1	0.01027	A1	86.85	80.24	2886	5555
01-389	F	1910	1930	01	1923	26	1963	1029	A1	0.06812	A1	22.11	189.24	435	9072
01-390	F	1887	1931	02	1925	260	1965	7400	A1	0.02527	A1	103.73	236.09	1358	6351
01-391	F	1914	1969	07	1950	520	1964	1	B6	0.0	Z9B	.02	.00	1	0
01-392	M	1913	1972	07	1950	520	1964	1	B6	0.0	Z9B	.02	.00	1	0
01-393	M	1937		07	1950	520	1972	2	B6	0.0	Z9B	.05	.00	2	0
01-394	F	1944		07	1950	520	1972	4	B3	0.0	Z9B	.14	.00	5	0
01-395	F	1945		07	1950	520	1972	5	B3	0.0	Z9B	.17	.00	7	0
01-396	M	1947		07	1950	520	1972	1	B6	0.0	Z9B	.02	.00	1	0
01-397	F	1950		07	1950	498	1973	4	B3	0.0	Z9B	.14	.00	5	0
01-398	M	1951		07	1951	429	1972	0	B6	0.0	Z9B	.00	.00	0	0
01-399	F	1953		07	1953	350	1972	1	B6	0.0	Z9B	.03	.00	1	0
01-400	M	1903		07	1961	156	1964	2	B6	0.0	Z9B	.01	.00	0	0
01-401	F	1910		07	1961	156	1964	3	B6	0.0	Z9B	.02	.00	1	0
01-402	F	1898		01	1920	18	1963	0	G6	0.05000	Z2	.00	.00	0	0
01-403	F	1912		02	1926	+0	1971	27	B2	0.01838	C3	1.57	6.86	107	516
01-404	M	1875	1945	67	1912	1716	1965	2800	A1	0.00189	A6	47.09	2.24	1523	134
01-405	F	1885	1957	67	1912	1716	1965	52	A1	0.01538	A6	2.25	1.34	106	98
01-406	M	1902	1969	67	1916	260	1963	18	B2	0.0	Z9B	.74	.00	51	0
01-407	M	1912		67	1930	416	1963	38	B2	0.0	Z9B	1.24	.00	75	0
01-408	F	1918		06	1934	416	1975	13	B2	0.0	Z9B	.68	.00	38	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
01-409	F	1914		06	1930	13	1975	34	B3	0.0	Z9B	1.96	.00	126	0
01-410	F	1920		06	1940	156	1975	33	B1	0.0	Z9B	1.63	.00	87	0
01-411	M	1915		06	1935	200	1973	8	B2	0.0	Z9C	.29	.00	17	0
01-412	M	1915	1970	02	1929	+0	1963	1	D6	0.01600	Z5D	.04	.04	2	3
01-413	F	1901	1965	01	1924	229	1964	11	G4	0.04400	Z2	.59	2.96	35	222
01-414	F	1897		06	1931	572	1974	1	B6	0.0	Z9E	.05	.00	3	0
01-415	M	1898		06	1921	520	1964	0	B6	0.0	Z9E	.00	.00	0	0
01-416	F	1908		01	1924	2	1963	9	G6	0.04900	Z2	.48	2.70	34	203
01-417	F	1907		01	1923	1	1963	0	G6	0.05000	Z2	.00	.00	0	0
01-418	M	1900	1972	06	1919	104	1963	6	G6	0.0	Z9	.24	.00	17	0
01-419	M	1895	1965	06	1916	260	1963	9	G6	0.0	Z9	.37	.00	24	0
01-420	F	1903	1967	06	1920	65	1963	2	G6	0.0	Z9	.11	.00	7	0
01-421	F	1888		06	1915	312	1963	8	G6	0.0	Z9	.46	.00	35	0
01-423	M	1897		06	1919	260	1973	22	B2	0.0	Z9B	.97	.00	70	0
01-424	F	1882		05	1924	+0	1964	280	G4	0.0	Z9	15.18	.00	1060	0
01-425	M	1933		07	1961	104	1964	0	B6	0.0	Z9B	.00	.00	0	0
01-426	F	1930		07	1961	104	1964	5	B3	0.0	Z9B	.06	.00	2	0
01-427	F	1960		07	1961	104	1964	5	E4	0.0	Z9	.06	.00	2	0
01-428	F	1957		07	1961	104	1964	2	E6	0.0	Z9	.02	.00	1	0
01-429	F	1897		06	1922	208	1974	0	B6	0.0	Z9B	.00	.00	0	0
01-430	M	1880	1969	02	1930	+0	1966	41	B2	0.02195	Z3	1.50	2.63	88	197
01-431	F	1901	1975	05	1922	52	1971	765	B1	0.0	Z9B	45.84	.00	3262	0
01-432	M	1895	1974	06	1915	520	1964	17	B2	0.0	Z9B	.69	.00	50	0
01-434	M	1880	1932	02	1927	156	1965	6126	A1	0.02189	A1	65.11	118.30	865	3250
01-435	F	1907		01	1925	5	1974	4	B3	0.00327	Z9B	.24	.30	17	23
01-436	F	1895		01	1927	180	1964	8	G6	0.01140	Z8	.41	.33	27	25
01-437	F	1910	1971	06	1931	104	1965	1	B6	0.0	Z9B	.05	.00	3	0
01-438	M	1867	1940	02	1925	208	1965	1850	A1	0.01372	A1	39.81	54.59	1163	3571
01-439	F	1880	1953	04	1922	8	1968	406	A2	0.0	Z9F	19.25	.00	971	0
01-440	F	1908		01	1924	204	1965	0	G6	0.03900	Z2	.00	.00	0	0
01-446	F	1907		01	1925	0	1964	0	G6	0.04400	Z2	.00	.00	0	0
01-447	F	1909		17	1925	110	1965	3	G6	0.01000	Z8	.16	.18	11	14
01-448	F	1907		01	1925	5	1964	25	G4	0.01140	Z8	1.34	1.74	92	131
01-449	F	1899		01	1922	2	1965	7	G6	0.03900	Z2	.39	2.86	28	215
01-450	M	1877	1936	06	1912	364	1956	0	A6	0.0	Z9A	.00	.00	0	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
01-454	F	1880	1970	01	1920	884	1974	1910	A1	0.0		112.54	.00	7448	0
01-456	M	1878	1948	02	1928	26	1965	74	A6	0.03648	Z9A	1.99	6.32	75	454
01-457	F	1904		06	1920	78	1964	8	G4	0.0	Z9	.45	.00	33	0
01-459	M	1886	1971	06	1921	52	1964	10	G6	0.0	Z9	.40	.00	27	0
01-460	M	1882	1966	06	1912	104	1964	0	G6	0.0	Z9	.00	.00	0	0
01-461	M	1914	1970	06	1930	26	1964	9	G4	0.0	Z9	.32	.00	19	0
01-464	F	1908		01	1927	4	1970	4	G6	0.00540	Z8	.23	.23	15	17
01-466	F	1902	1946	01	1920	52	1965	0	A6	0.03800	Z2A	.00	.00	0	0
01-468	F	1910		01	1927	0	1965	0	G6	0.01000	Z8	.00	.00	0	0
01-469	M	1894		06	1918	52	1965	4	G6	0.0	Z9	.17	.00	13	0
01-470	F	1912		01	1927	70	1965	0	G6	0.01000	Z8	.00	.00	0	0
01-472	F	1896	1969	06	1919	156	1965	7	G6	0.0	Z9	.40	.00	27	0
01-474	F	1904		07	1924	100	1974	0	B6	0.0	Z9B	.00	.00	0	0
01-475	F	1901		01	1928	4	1974	0	B6	0.00330	Z8B	.00	.00	0	0
01-476	F	1909		07	1927	71	1972	4	B3	0.00420	Z8B	.23	.21	15	16
01-477	F	1897		02	1925	+0	1965	1240	B1	0.00475	B2	67.22	41.37	4633	3110
01-478	F	1914		01	1935	24	1965	0	G6	0.0	Z9	.00	.00	0	0
01-479	F	1912		01	1927	1	1965	3	G6	0.01000	Z8	.16	.16	11	12
01-480	F	1915		01	1927	1	1965	38	G6	0.01000	Z8	2.01	2.04	135	153
01-481	F	1909		01	1927	14	1965	0	G6	0.01000	Z8	.00	.00	0	0
01-482	F	1912		01	1927	4	1974	1	B6	0.00330	Z8B	.06	.06	4	4
01-483	M	1907		17	1922	104	1975	0	B6	0.01184	Z2B	.00	.00	0	0
01-484	F	1908	1974	01	1926	0	1965	0	G6	0.01000	Z8	.00	.00	0	0
01-485	M	1870	1951	05	1911	1300	1965	340	A1	0.0	Z9A	10.52	.00	488	0
01-486	F	1907		01	1923	6	1974	0	B6	0.01318	Z2B	.00	.00	0	0
01-487	F	1911		07	1927	565	1971	2	B6	0.00470	Z8B	.11	.05	7	4
01-489	F	1910		01	1926	348	1965	225	G6	0.01000	Z8	11.48	8.47	745	637
01-490	F	1908		01	1924	17	1974	2	B6	0.01318	Z2B	.12	.69	8	52
01-491	F	1922	1966	01	1943	728	1963	7	G6	0.0	Z9	.20	.00	7	0
01-492	F	1900		06	1921	260	1973	1	B6	0.0	Z9B	.06	.00	4	0
01-493	M	1893	1975	06	1927	1820	1973	4	B3	0.0	Z9C	.12	.00	6	0
01-494	M	1906	1966	06	1926	999	1966	0	G6	0.0	Z9	.00	.00	0	0
01-495	F	1908		01	1924	4	1965	0	G6	0.03900	Z2	.00	.00	0	0
01-496	F	1918		07	1934	106	1966	3	G6	0.0	Z9	.14	.00	8	0
01-497	F	1902		01	1921	8	1966	13	G6	0.03400	Z2	.75	6.00	54	451

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
01-498	F	1897		06	1920	104	1973	2	B6	0.0	Z9C	.12	.00	9	0
01-501	M	1867	1937	02	1926	156	1966	2500	A1	0.00760	A1	45.69	37.10	1102	2149
01-503	M	1936		08	1936	39	1966	0	B6	0.0	Z93	.00	.00	0	0
01-504	F	1913		01	1927	2	1967	0	B6	0.0	Z9B	.00	.00	0	0
01-505	F	1902		01	1927	1	1966	9	G4	0.00880	Z8	.48	.49	32	36
01-506	F	1897		04	1923	4	1966	7	B3	0.0	Z9C	.39	.00	28	0
01-507	F	1909		01	1927	22	1974	8	B2	0.00313	Z8B	.47	.44	31	33
01-508	F	1906	1968	01	1944	52	1956	30	G6	0.0	Z9	1.18	.00	50	0
01-509	F	1943		08	1943	39	1967	0	B6	0.0	Z9B	.00	.00	0	0
01-510	F	1897		01	1927	12	1966	38	G6	0.00880	Z8	2.03	2.02	136	152
01-511	F	1908		07	1927	9	1974	0	B6	0.00330	Z8B	.00	.00	0	0
01-512	F	1895		04	1912	13	1973	0	B6	0.0	Z9B	.00	.00	0	0
01-514	F	1904		07	1924	2184	1975	0	B6	0.0	Z9B	.00	.00	0	0
01-515	F	1886		05	1940	0	1966	4	G6	0.0	Z9	.17	.00	9	0
01-516	F	1907		01	1927	2	1967	7	G6	0.00780	Z8	.38	.38	25	29
01-518	M	1912		05	1949	-0	1966	15	G4	0.0	Z9	.37	.00	17	0
01-519	M	1919		06	1937	260	1967	13	G6	0.0	Z9	.41	.00	23	0
01-520	F	1882	1969	02	1930	-0	1967	670	B1	0.00492	B2	34.88	15.44	2044	1158
01-521	M	1910		06	1942	520	1972	25	B2	0.0	Z9B	.75	.00	36	0
01-522	M	1905		06	1928	1924	1969	240	B1	0.0	Z9B	6.06	.00	286	0
01-523	M	1917		06	1942	312	1963	30	G4	0.0	Z9	.87	.00	43	0
01-525	M	1923		06	1943	104	1968	17	G6	0.0	Z9	.50	.00	25	0
01-526	M	1921		06	1945	38	1973	30	B2	0.0	Z9B	.96	.00	47	0
01-529	M	1920		06	1943	260	1975	14	B2	0.0	Z9B	.46	.00	23	0
01-530	M	1920	1971	06	1943	104	1963	52	B1	0.0	Z9B	1.54	.00	71	0
01-531	M	1918		06	1941	354	1974	13	B2	0.0	Z9B	.43	.00	22	0
01-532	M	1914	1973	06	1945	133	1968	1	G6	0.0	Z9	.03	.00	1	0
01-533	F	1903		04	1911	+0	1969	4	G6	0.0	Z9	.26	.00	21	0
01-536	M	1916		06	1943	286	1968	17	G6	0.0	Z9	.48	.00	24	0
01-537	M	1917	1971	06	1944	208	1968	59	B1	0.0	Z9B	1.67	.00	74	0
01-540	M	1890		07	1940	260	1968	0	G6	0.0	Z9	.00	.00	0	0
01-543	M	1920		06	1943	167	1975	19	B2	0.0	Z9B	.64	.00	32	0
01-544	F	1879	1953	02	1930	+0	1968	93	A1	0.00430	A3	3.78	1.65	158	121
01-546	F	1897		01	1914	52	1957	0	G6	0.0	Z9	.00	.00	0	0
01-547	F	1897		06	1920	104	1975*	4	B3	0.0	Z9B	.25	.00	18	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
01-548	M	1917		02	1930	+0	1972	5	B3	0.00200	Z5B	.20	.07	13	5
01-552	M	1907		06	1936	104	1967	20	G4	0.0	Z9	.67	.00	38	0
01-553	F	1910		01	1948	988	1967	0	G6	0.0	Z9	.00	.00	0	0
01-554	F	1928		01	1952	780	1967	490	G4	0.0	Z9	7.66	.00	247	0
01-555	F	1894		01	1921	2	1975	0	B6	0.01155	Z2B	.00	.00	0	0
01-556	F	1910		01	1927	0	1967	0	G6	0.00780	Z8	.00	.00	0	0
01-557	F	1908		01	1925	32	1972	5	B3	0.00420	Z8B	.29	.36	20	27
01-558	M	1913		02	1927	130	1973	362	B2	0.00110	B2	14.86	3.76	980	282
01-562	F	1901	1931	01	1920	52	1970	10300	A1	0.0	Z9A	278.45	.00	7143	0
01-565	F	1892	1957	05	1925	26	1970	1600	A2	0.0	Z9A	76.92	.00	3946	0
01-567	M	1885	1949	02	1925	+0	1970	1100	A2	0.00400	A2	32.66	31.09	1400	2282
01-568	M	1907	1928	05	1927	+0	1969	4900	A1	0.0	Z9A	27.87	.00	183	0
01-570	F	1908		01	1926	260	1968	10	G4	0.0	Z9	.54	.00	35	0
01-571	F	1911		01	1928	44	1968	1	B6	0.00680	Z8B	.05	.05	4	3
01-573	F	1892	1945	01	1916	312	1970	670	A1	0.00195	F3	28.98	27.09	1307	2000
01-574	F	1885	1937	05	1924	77	1968	2730	A1	0.0	Z9A	79.98	.00	2255	0
01-575	M	1910		01	1950	1196	1973	2	B6	0.0	Z9B	.03	.00	1	0
01-576	F	1930		01	1945	780	1968	160	B1	0.0	Z9B	4.92	.00	196	0
01-578	F	1904	1930	05	1926	17	1968	2000	A2	0.0	Z9A	32.03	.00	452	0
01-579	F	1928	1928	08	1928	26	1973	2	A1	0.00289	Z2A	.03	.02	1	0
01-580	F	1894		01	1918	52	1972	1	B6	0.0	Z9B	.06	.00	5	0
01-581	M	1918		06	1946	52	1968	10	G4	0.0	Z9	.28	.00	13	0
01-582	F	1893		06	1917	24	1974	0	B6	0.0	Z9B	.00	.00	0	0
01-583	M	1890	1969	06	1918	104	1968	0	G6	0.00250	Z7	.00	.00	0	0
01-584	F	1908		01	1926	260	1968	10	B2	0.0	Z9B	.54	.00	35	0
01-585	F	1906	1969	01	1925	26	1968	0	B6	0.00450	Z5B	.00	.00	0	0
01-586	F	1879	1973	05	1924	+0	1968	130	G6	0.0	Z9	7.41	.00	504	0
01-588	F	1908		01	1929	104	1968	5	G6	0.0	Z9	.26	.00	17	0
01-589	M	1907		06	1927	78	1964	2	G6	0.0	Z9	.07	.00	5	0
01-590	M	1929		08	1929	39	1972	3	B6	0.01720	Z2C	.12	.37	8	28
01-591	F	1891	1975	01	1918	52	1973	0	G6	0.00016	Z7	.00	.00	0	0
01-592	F	1903	1971	01	1917	6	1968	0	G6	0.0	Z9	.00	.00	0	0
01-594	M	1926		01	1962	34	1975	2	B6	0.0	Z9B	.04	.00	1	0
01-595	F	1897		01	1917	130	1969	5	G6	0.0	Z9	.31	.00	23	0
01-597	F	1923		01	1940	364	1973	1	B6	0.0	Z9C	.05	.00	2	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
01-598	M	1879	1953	06	1941	+0	1952	400	G6	0.0	Z9	7.92	.00	220	0
01-599	F	1909		01	1927	7	1973	2	B6	0.00370	Z8B	.12	.11	8	9
01-601	F	1902		01	1918	6	1969	0	G6	0.00460	Z7	.00	.00	0	0
01-603	F	1894		01	1915	676	1968	7	G6	0.00450	Z5	.41	.55	30	41
01-604	F	1896		01	1914	52	1971	1	B6	0.0	Z9B	.06	.00	5	0
01-608	F	1906		01	1927	11	1974	0	G6	0.00330	Z2B	.00	.00	0	0
01-609	F	1906		01	1926	366	1973	3	B6	0.0	Z9B	.17	.00	11	0
01-610	M	1904	1969	06	1919	208	1968	10	G6	0.0	Z9	.42	.00	28	0
01-612	F	1859	1936	01	1923	255	1972	18	A1	0.00680	Z4A	.52	1.12	14	71
01-613	F	1906	1936	06	1923	265	1972	658	A1	0.00680	F2	17.61	33.02	450	1987
01-614	M	1882	1922	06	1920	+0	1974	24	A2	0.0	Z9	.20	.00	2	0
01-617	M	1922		08	1922	39	1973	4	B3	0.00020	Z3B	.18	.02	12	1
01-619	F	1909		01	1927	52	1969	0	G6	0.0	Z9	.00	.00	0	0
01-621	F	1908		01	1924	2	1975	7	B2	0.01135	Z2B	.43	2.41	30	181
01-625	F	1911		01	1927	468	1968	6	G6	0.0	Z9	.31	.00	19	0
01-626	F	1932		08	1932	39	1971	0	B6	0.0	Z9B	.00	.00	0	0
01-627	F	1897		01	1917	52	1970	0	G6	0.0	Z9	.00	.00	0	0
01-628	F	1908		01	1925	312	1975	0	B6	0.0	Z9B	.00	.00	0	0
01-629	F	1892		01	1926	260	1969	12	G6	0.0	Z9	.65	.00	43	0
01-633	F	1878	1926	05	1925	4	1970	2600	A2	0.0	Z9A	20.28	.00	130	0
01-635	M	1880	1937	06	1918	312	1973	1900	A1	0.0	Z9A	45.47	.00	1509	0
01-640	F	1908		01	1924	21	1969	34	G6	0.00420	Z5	1.96	1.91	136	143
01-653	F	1910		01	1925	78	1969	7	G6	0.00420	Z5	.40	.33	27	25
01-659	F	1912		01	1928	26	1969	11	G6	0.0	Z9	.60	.00	40	0
01-660	F	1881	1957	04	1932	+0	1970	15	A6	0.0	Z9A	.64	.00	28	0
01-661	M	1874	1934	06	1914	572	1974	2	A6	0.0	Z9	.03	.00	1	0
01-663	M	1927		08	1927	39	1969	11	G4	0.0	Z9	.43	.00	29	0
01-665	M	1923		08	1923	39	1969	0	G6	0.0	Z9	.00	.00	0	0
01-667	F	1918		01	1941	234	1972	0	B6	0.0	Z9B	.00	.00	0	0
01-668	M	1933		07	1964	+0	1974	1	B6	0.0	Z9	.03	.00	1	0
01-669	F	1917		01	1934	104	1969	0	G6	0.0	Z9	.00	.00	0	0
01-670	M	1897		04	1928	+0	1969	0	G6	0.0	Z9	.00	.00	0	0
01-671	F	1923		01	1941	260	1972	2	B6	0.0	Z9B	.09	.00	5	0
01-674	M	1908		01	1931	1716	1973	0	B6	0.0	Z9B	.00	.00	0	0
01-681	F	1904		07	1920	4	1972	0	G6	0.0	Z9	.00	.00	0	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
01-684	F	1894	1974	01	1917	1	1973	0	G6	0.0	Z9	.00	.00	0	0
01-688	M	1868	1948	07	1920	+0	1972	0	A6	0.0	Z9A	.00	.00	0	0
01-690	M	1878	1940	04	1918	+0	1970	21	A1	0.0	Z9A	.60	.00	24	0
01-691	F	1913	1974	04	1935	0	1971	0	B6	0.0	Z9B	.00	.00	0	0
01-692	M	1885	1974	02	1925	+0	1970	30	G6	0.00680	Z5	1.24	2.00	84	150
01-694	M	1886	1953	54	1928	+0	1971	10000	F4	0.0	Z9	303.27	.00	13346	0
01-701	M	1892		06	1916	312	1970	0	G6	0.0	Z9	.00	.00	0	0
01-706	F	1908		07	1923	100	1975	0	B6	0.01149	Z2	.00	.00	0	0
01-707	F	1908	1974	01	1927	1	1971	0	G6	0.00470	Z8	.00	.00	0	0
01-710	F	1901		01	1925	289	1970	0	G6	0.00370	Z5	.00	.00	0	0
01-711	F	1905		01	1925	312	1970	0	G6	0.00370	Z5	.00	.00	0	0
01-715	F	1907		01	1927	5	1973	2	B6	0.00370	Z8B	.12	.12	8	9
01-717	M	1910		27	1927	13	1974	4	B6	0.00420	Z5	.17	.21	11	16
01-728	F	1912		01	1927	6	1973	3	B3	0.00370	Z8B	.17	.17	12	13
01-739	F	1856	1928	05	1926	7	1972	11500	A1	0.0	Z9A	128.96	.00	1226	0
03-005	M	1917		07	1948	+0	1973	0	B6	0.0	Z9C	.00	.00	0	0
03-008	F	1934		08	1934	39	1971	0	B6	0.0	Z9C	.00	.00	0	0
03-009	F	1918		01	1941	104	1972	1	B6	0.0	Z9C	.04	.00	2	0
03-101	F	1908	1971	05	1931	15	1963	1580	C2	0.0	Z9	76.09	.00	4523	0
03-102	M	1908		05	1931	15	1973	628	B1	0.0	Z9C	24.90	.00	1575	0
03-103	F	1868	1952	05	1931	15	1951	420	F4	0.0	Z9	15.82	.00	621	0
03-104	F	1880	1941	05	1931	15	1931	13900	E4	0.0	Z9	89.72	.00	2215	0
03-105	M	1903	1957	05	1931	16	1951	2600	E4	0.0	Z9	69.93	.00	3143	0
03-106	F	1876	1953	05	1931	16	1931	4600	B2	0.0	Z9	29.44	.00	1189	0
03-107	F	1884	1957	05	1931	16	1931	3600	B2	0.0	Z9	23.04	.00	1036	0
03-108	F	1875	1953	05	1931	16	1932	1900	E4	0.0	Z9	13.81	.00	558	0
03-109	F	1904	1957	05	1931	18	1953	630	B2	0.0	Z9	24.93	.00	1120	0
03-110	F	1899	1967	05	1931	20	1964	584	B1	0.0	Z9	28.56	.00	1583	0
03-111	F	1909		05	1931	20	1973	879	B2	0.0	Z9C	48.76	.00	3082	0
03-112	F	1899	1968	05	1931	26	1960	5310	B1	0.0	Z9	242.44	.00	13669	0
03-113	F	1914	1946	05	1931	38	1932	1300	E4	0.0	Z9	7.77	.00	244	0
03-114	F	1901	1968	05	1931	36	1964	949	B1	0.0	Z9	46.30	.00	2606	0
03-115	F	1911		05	1931	26	1973	745	B1	0.0	Z9C	41.30	.00	2608	0
03-116	F	1907		05	1931	25	1973	1411	B1	0.0	Z9C	78.23	.00	4941	0
03-117	M	1898	1957	05	1931	45	1953	1540	B2	0.0	Z9	43.25	.00	1931	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
03-118	F	1898	1955	05	1931	41	1953	3090	B2	0.0	Z9	121.60	.00	5159	0
03-119	F	1880	1960	05	1931	7	1959	1038	C2	0.0	Z9	46.69	.00	2256	0
03-120	F	1879	1937	05	1931	11	1932	5300	E4	0.0	Z9	39.74	.00	721	0
03-121	F	1911	1972	05	1931	9	1964	371	B1	0.0	Z9	18.17	.00	1099	0
03-122	M	1908	1942	05	1931	10	1931	6500	E4	0.0	Z9	13.14	.00	345	0
03-123	M	1914	1937	05	1931	9	1931	9700	B2	0.0	Z9	19.84	.00	361	0
03-124	M	1910	1942	05	1931	9	1931	4200	B2	0.0	Z9	8.59	.00	226	0
03-125	F	1913		05	1931	11	1973	556	B1	0.0	Z9C	30.88	.00	1954	0
03-126	F	1910	1965	05	1931	20	1965	1300	C2	0.0	Z9	64.57	.00	3449	0
03-127	F	1908		05	1931	26	1962	565	C2	0.0	Z9	26.71	.00	1687	0
03-135	M	1905		05	1931	+0	1973	1431	B1	0.0	Z9C	56.84	.00	3603	0
03-139	M	1908		05	1933	11	1973	373	C2	0.0	Z9C	14.42	.00	886	0
03-140	M	1905	1937	05	1933	11	1961	500	F4	0.0	Z9	5.77	.00	82	0
03-141	M	1906	1963	05	1933	11	1962	961	C2	0.0	Z9	31.42	.00	1550	0
03-201	F	1909	1963	04	1922	+0	1962	2968	C2	0.0	Z9	160.90	.00	9741	0
03-202	M	1895		05	1925	+0	1960	1800	G4	0.0	Z9	65.03	.00	4482	0
03-203	F	1903	1973	05	1933	+0	1959	84	C2	0.0	Z9	3.64	.00	217	0
03-204	F	1896	1970	04	1922	+0	1960	21	C2	0.0	Z9	1.11	.00	74	0
03-205	F	1900		05	1929	15	1968	291	C2	0.0	Z9	15.54	.00	1012	0
03-206	M	1914	1975	05	1936	4	1973	3297	B1	0.0	Z9C	122.53	.00	7176	0
03-207	F	1879	1969	04	1922	416	1960	755	C2	0.0	Z9	37.54	.00	2344	0
03-209	M	1894	1960	05	1925	572	1973	1105	A1	0.0	Z9A	36.35	.00	1776	0
03-210	M	1906	1958	05	1926	+0	1957	1350	C2	0.00089	F2	45.79	1.77	2360	132
03-211	M	1890		05	1923	20	1960	10	C3	0.0	Z9	.37	.00	26	0
03-212	F	1902	1951	04	1927	+0	1951	1300	B2	0.00130	F1	54.04	1.30	2317	95
03-213	F	1892	1955	05	1925	+0	1952	6570	B2	0.0	Z9	230.34	.00	14358	0
03-214	F	1895	1966	05	1925	+0	1954	1382	C2	0.0	Z9F	73.94	.00	4477	0
03-215	M	1896	1971	05	1925	+0	1951	3630	C2	0.0	Z9	133.07	.00	8685	0
03-216	F	1907	1961	05	1922	+0	1951	530	C2	0.0	Z9F	28.36	.00	1662	0
03-217	M	1912	1974	05	1921	+0	1953	460	C2	0.0	Z9	48.27	.00	1308	0
03-218	M	1908		05	1924	+0	1972	3	B3	0.0	Z9C	.14	.00	10	0
03-219	F	1888	1961	04	1919	+0	1951	60	B2	0.0	Z9	2.90	.00	178	0
03-220	M	1920		04	1928	208	1974	131	B1	0.0	Z9C	5.31	.00	342	0
03-221	M	1908	1963	05	1924	+0	1957	620	C2	0.0	Z9	21.72	.00	1273	0
03-222	M	1872	1954	05	1922	+0	1951	1600	B2	0.0	Z9	52.42	.00	2702	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
03-223	F	1886	1968	05	1929	156	1951	4200	B2	0.0	Z9	160.72	.00	9181	0
03-224	M	1869	1960	54	1922	364	1951	5400	B2	0.0	Z9	165.05	.00	8929	0
03-225	M	1922		04	1929	+0	1973	33	B1	0.0	Z9C	1.32	.00	86	0
03-226	M	1874	1953	05	1934	39	1951	10700	B2	0.0	Z9	262.45	.00	9588	0
03-227	F	1878	1952	05	1930	+0	1952	1000	B2	0.0	Z9	39.73	.00	1612	0
03-228	M	1900	1955	05	1927	+0	1951	5600	B2	0.0	Z9	166.26	.00	7866	0
03-230	F	1899		05	1927	+0	1974	422	B1	0.0	Z9C	24.88	.00	1670	0
03-231	F	1879	1973	05	1939	+0	1952	60	E4	0.0	Z9	1.81	.00	97	0
03-232	F	1898	1957	05	1917	+0	1956	4700	D2	0.0	Z9	251.47	.00	14981	0
03-233	F	1879	1947	05	1922	+0	1947	4000	C4	0.0	Z9	169.83	.00	7473	0
03-234	F	1890	1965	05	1915	+0	1965	920	C2	0.0	Z9	56.01	.00	3861	0
03-235	F	1900	1968	05	1928	+0	1965	1290	C2	0.0	Z9	67.16	.00	4001	0
03-236	F	1880	1961	05	1927	+0	1951	500	B2	0.0	Z9	20.78	.00	1114	0
03-237	F	1890		04	1923	156	1961	3	C6	0.0	Z9	.16	.00	11	0
03-238	M	1883	1954	05	1926	+0	1951	13900	B2	0.0	Z9	421.55	.00	19944	0
03-239	F	1883	1953	05	1925	+0	1970	10000	A1	0.0	Z9A	450.35	.00	21306	0
03-240	F	1916	1955	05	1930	+0	1973	4320	A1	0.0	Z9A	183.42	.00	8071	0
03-401	F	1900	1963	01	1923	95	1960	2287	C2	0.0	Z9	117.51	.00	6896	0
03-402	F	1905		01	1923	260	1974	1223	B1	0.00010	F2	74.06	2.93	5138	220
03-403	F	1915	1964	01	1935	572	1957	8	C3	0.0	Z9	.27	.00	11	0
03-404	F	1897		01	1923	195	1975	577	B1	0.0	Z9C	35.31	.00	2449	0
03-405	F	1904		16	1924	273	1962	625	C2	0.0	Z9	31.76	.00	2142	0
03-406	F	1914		01	1935	481	1972	7	B3	0.0	Z9C	.34	.00	19	0
03-407	F	1905	1961	01	1923	1196	1958	1545	B1	0.00022	F2	76.36	.98	4286	73
03-408	F	1908	1959	01	1924	676	1957	160	C2	0.0	Z9	7.72	.00	414	0
03-409	F	1923		01	1942	78	1972	8	B2	0.0	Z9C	.38	.00	20	0
03-410	F	1895	1974	01	1923	104	1957	60	C2	0.0	Z9	2.94	.00	203	0
03-411	F	1908		01	1931	572	1972	0	B6	0.0	Z9C	.00	.00	0	0
03-412	F	1894		01	1922	134	1975	180	B1	0.0	Z9C	11.15	.00	786	0
03-413	F	1917		01	1939	169	1972	1	B6	0.0	Z9C	.04	.00	2	0
03-414	F	1921		01	1946	557	1972	3	B6	0.0	Z9C	.11	.00	5	0
03-415	F	1911	1973	01	1930	780	1957	15	C3	0.0	Z9	.55	.00	30	0
03-416	F	1907		01	1924	65	1974	795	B1	0.0	Z9C	48.09	.00	3331	0
03-417	F	1909	1966	01	1924	60	1964	617	C2	0.0	Z9	33.20	.00	2023	0
03-418	F	1896		61	1925	602	1972	4	B3	0.0	Z9C	.21	.00	13	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
03-419	F	1906		01	1924	208	1962	679	C2	0.0	Z9	35.34	.00	2436	0
03-420	F	1906	1960	01	1922	212	1957	18	C2	0.0	Z9	.88	.00	49	0
03-421	F	1908		01	1924	117	1974	5	B3	0.0	Z9C	.30	.00	21	0
03-422	F	1907		06	1925	104	1975	11	B2	0.0	Z9C	.67	.00	45	0
03-423	F	1907	1972	01	1923	641	1962	591	C2	0.0	Z9	30.98	.00	2064	0
03-424	F	1905		01	1923	186	1973	203	B1	0.0	Z9C	12.16	.00	844	0
03-425	F	1916		01	1935	260	1973	2	B6	0.0	Z9C	.10	.00	6	0
03-426	F	1906		01	1924	2184	1972	139	B1	0.0	Z9C	8.19	.00	565	0
03-427	F	1906		01	1925	823	1973	12	B2	0.0	Z9C	.74	.00	50	0
03-428	F	1908		01	1925	164	1974	493	B1	0.0	Z9C	29.51	.00	2021	0
03-429	F	1908		01	1923	208	1974	1169	B1	0.0	Z9C	70.79	.00	4911	0
03-430	F	1922		01	1941	468	1971	4	B3	0.0	Z9C	.19	.00	9	0
03-431	F	1901		01	1922	156	1963	1297	C2	0.0	Z9	69.84	.00	4908	0
03-432	F	1902		01	1923	112	1974	25	B2	0.0	Z9C	1.51	.00	105	0
03-433	F	1904		01	1924	117	1964	1052	C2	0.0	Z9	56.28	.00	3879	0
03-434	F	1920		01	1941	125	1975	5	B2	0.0	Z9C	.23	.00	12	0
03-435	F	1912		01	1935	104	1971	3	B6	0.0	Z9C	.13	.00	8	0
03-436	F	1910		01	1926	619	1975	8	B3	0.0	Z9C	.47	.00	29	0
03-437	F	1906		01	1926	52	1957	53	C2	0.0	Z9	2.59	.00	175	0
03-438	F	1908		01	1925	8	1957	0	C6	0.0	Z9	.00	.00	0	0
03-439	F	1906		01	1925	56	1957	0	C6	0.0	Z9	.00	.00	0	0
03-440	F	1908		01	1925	3	1974	1	B6	0.0	Z9C	.06	.00	4	0
03-441	F	1905		01	1925	528	1957	56	C2	0.0	Z9	2.68	.00	184	0
03-442	F	1904		01	1924	13	1957	13	C3	0.0	Z9	.64	.00	44	0
03-443	F	1914		01	1935	316	1971	0	B6	0.0	Z9C	.00	.00	0	0
03-444	F	1907		01	1925	56	1974	12	B2	0.0	Z9C	.70	.00	48	0
03-445	F	1905	1974	01	1922	260	1966	1367	C2	0.0	Z9	75.99	.00	5237	0
03-446	F	1903		01	1921	260	1974	48	B1	0.0	Z9C	2.91	.00	204	0
03-447	F	1906		01	1924	4	1958	2	C6	0.0	Z9	.10	.00	7	0
03-448	F	1903	1963	01	1924	19	1958	25	C2	0.0	Z9	1.24	.00	73	0
03-449	F	1905	1974	01	1922	1456	1964	1135	B1	0.0	Z9	61.51	.00	4239	0
03-450	F	1910		01	1924	697	1974	8	B2	0.0	Z9C	.47	.00	32	0
03-451	F	1922		01	1940	524	1972	1	B6	0.0	Z9C	.04	.00	2	0
03-452	F	1909		16	1925	728	1974	15	B1	0.0	Z9C	.85	.00	53	0
03-453	F	1907		01	1924	8	1973	4	B3	0.0	Z9C	.23	.00	16	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	
03-454	F	1914		06	1934	572	1958	48	C2	0.0	Z9	1.72	.00	95	
03-455	F	1906		01	1922	56	1975	491	B1	0.00054	F1	30.63	9.81	2179	
03-456	F	1921	1965	01	1943	416	1958	33	C2	0.0	Z9	.90	.00	32	
03-457	F	1915		01	1939	520	1972	1	B6	0.0	Z9C	.04	.00	2	
03-458	F	1925		01	1946	1300	1971	31	B2	0.0	Z9C	.63	.00	21	
03-459	F	1906		01	1924	43	1973	820	B1	0.0	Z9C	49.18	.00	3416	
03-460	F	1905		01	1923	19	1972	2	B6	0.0	Z9C	.14	.00	10	
03-461	F	1896		01	1922	6	1958	6	C3	0.0	Z9	.31	.00	22	
03-462	F	1906		01	1922	2756	1975	240	B1	0.0	Z9C	14.76	.00	1031	
03-463	F	1918	1966	01	1942	832	1958	33	C2	0.0	Z9	.53	.00	18	
03-464	F	1907		01	1923	104	1974	0	C6	0.0	Z9C	.02	.00	2	
03-465	F	1908		01	1925	8	1958	2	C6	0.0	Z9	.10	.00	7	
03-466	F	1904		01	1924	10	1972	0	B6	0.0	Z9C	.00	.00	0	
03-467	F	1911		01	1926	416	1972	7	B3	0.0	Z9C	.40	.00	26	
03-468	F	1908		01	1926	121	1958	29	C2	0.0	Z9	1.37	.00	92	
03-469	F	1903	1960	01	1925	30	1958	10	C3	0.0	Z9	.49	.00	27	
03-470	F	1926		01	1943	247	1971	3	B3	0.0	Z9C	.14	.00	7	
03-471	F	1908		01	1926	91	1958	13	C3	0.0	Z9	.62	.00	42	
03-472	F	1922		01	1941	247	1972	5	B3	0.0	Z9C	.24	.00	12	
03-473	F	1904	1965	01	1922	156	1962	1170	C2	0.0	Z9	62.17	.00	3793	
03-474	F	1909		01	1925	21	1958	19	C2	0.0	Z9	.93	.00	64	0
03-475	F	1903	1962	01	1921	65	1958	0	C6	0.0	Z9	.00	.00	0	0
03-476	F	1895	1970	01	1927	6	1958	0	C6	0.0	Z9	.00	.00	0	0
03-477	F	1911		01	1925	11	1972	3	B3	0.0	Z9C	.18	.00	12	0
03-478	F	1907		01	1924	8	1958	5	C6	0.0	Z9	.25	.00	17	0
03-479	F	1908		01	1924	52	1975	27	B1	0.00017	F2	1.64	.13	114	10
03-480	F	1909		01	1924	10	1975	2	B3	0.0	Z9	.13	.00	9	0
03-481	F	1922		01	1942	481	1972	9	B2	0.0	Z9C	.37	.00	18	0
03-482	F	1927		01	1944	130	1972	3	B6	0.0	Z9C	.11	.00	6	0
03-483	F	1901		01	1922	177	1975	1	B6	0.0	Z9C	.06	.00	4	0
03-484	F	1888	1966	01	1919	156	1962	1622	C2	0.0	Z9	89.62	.00	5807	0
03-485	F	1909		01	1929	364	1958	0	C6	0.0	Z9	.00	.00	0	0
03-486	F	1909		01	1925	156	1966	267	C2	0.0	Z9	14.57	.00	998	0
03-487	F	1907	1964	61	1924	676	1958	367	C2	0.0	Z9	18.00	.00	1055	0
03-488	F	1907	1975	01	1922	26	1958	170	C2	0.0	Z9	8.69	.00	621	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
03-489	F	1911	1964	01	1926	73	1958	120	C2	0.0	Z9	5.73	.00	326	0
03-490	M	1904		07	1925	177	1973	5	B3	0.0	Z9C	.19	.00	13	0
03-491	F	1908		01	1924	2	1973	41	B2	0.0	Z9C	2.44	.00	170	0
03-492	F	1928		01	1946	325	1973	5	B3	0.0	Z9C	.19	.00	9	0
03-493	F	1893		01	1920	199	1975	6	B3	0.0	Z9C	.35	.00	25	0
03-494	F	1902		01	1924	177	1959	4	C3	0.0	Z9	.20	.00	14	0
03-495	F	1910		01	1923	7	1972	0	B6	0.0	Z9C	.00	.00	0	0
03-496	F	1907		01	1923	8	1972	0	B6	0.0	Z9C	.00	.00	0	0
03-497	F	1903	1970	01	1923	260	1959	16	C2	0.0	Z9	.80	.00	52	0
03-498	F	1905		67	1923	1040	1972	2	B6	0.0	Z9C	.08	.00	5	0
03-499	F	1905		01	1924	56	1973	199	B1	0.00320	C3	11.92	13.82	827	1039
03-500	F	1901	1959	01	1922	8	1959	0	C6	0.0	Z9	.00	.00	0	0
03-501	F	1912		01	1928	8	1959	7	C3	0.0	Z9	.33	.00	22	0
03-502	F	1887	1964	01	1918	156	1959	170	C2	0.0	Z9	9.15	.00	585	0
03-503	F	1894	1960	01	1922	112	1959	125	C2	0.0	Z9	6.41	.00	362	0
03-504	F	1905		01	1922	30	1974	9	B2	0.0	Z9C	.56	.00	40	0
03-505	F	1907		01	1923	1300	1975	159	B2	0.0	Z9C	10.32	.00	716	0
03-506	F	1917		01	1935	1872	1975	9	B2	0.0	Z9C	.33	.00	13	0
03-507	F	1907	1962	01	1923	6	1959	12	C3	0.0	Z9	.62	.00	36	0
03-508	F	1905	1963	01	1923	8	1959	10	C3	0.0	Z9	.51	.00	31	0
03-509	F	1907		01	1924	2548	1973	28	B1	0.0	Z9C	1.65	.00	114	0
03-510	F	1907		01	1923	2028	1962	729	C2	0.0	Z9	38.21	.00	2651	0
03-511	F	1910		01	1946	673	1959	10	C3	0.0	Z9	.16	.00	6	0
03-512	F	1906		01	1925	26	1959	11	C3	0.0	Z9	.55	.00	38	0
03-513	F	1908		01	1925	48	1974	73	B1	0.0	Z9	4.39	.00	301	0
03-514	F	1909		01	1925	208	1959	26	C2	0.0	Z9	1.29	.00	88	0
03-515	F	1908		01	1925	156	1959	11	C3	0.0	Z9	.54	.00	37	0
03-516	F	1911		01	1925	624	1972	7	B3	0.0	Z9C	.43	.00	30	0
03-517	F	1922		01	1943	260	1972	1	B6	0.0	Z9C	.03	.00	1	0
03-518	F	1921		01	1940	464	1972	8	B3	0.0	Z9C	.33	.00	17	0
03-519	F	1903		01	1924	8	1959	98	C2	0.0	Z9	4.95	.00	345	0
03-520	F	1907		01	1925	780	1974	112	C2	0.0	Z9	6.68	.00	458	0
03-521	F	1907	1961	01	1925	39	1959	10	C3	0.0	Z9	.50	.00	27	0
03-522	F	1898		01	1921	52	1975	111	B2	0.0	Z9C	7.03	.00	506	0
03-523	F	1900		01	1923	30	1972	15	B2	0.0	Z9C	.88	.00	62	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
03-524	F	1903		01	1925	260	1972	48	B2	0.0	Z9C	2.79	.00	191	0
03-525	F	1911		01	1931	2132	1959	19	C2	0.0	Z9	.60	.00	25	0
03-526	F	1896		01	1925	52	1959	0	C6	0.0	Z9	.00	.00	0	0
03-527	F	1909		01	1925	130	1959	5	C3	0.0	Z9	.25	.00	17	0
03-528	F	1904		01	1922	524	1959	1630	C2	0.0	Z9	82.40	.00	5754	0
03-529	F	1902		01	1921	104	1974	72	B6	0.0	Z9C	4.50	.00	322	0
03-530	F	1907	1965	01	1923	91	1963	474	C2	0.0	Z9	25.40	.00	1541	0
03-531	F	1906		01	1925	403	1959	41	C2	0.0	Z9	2.03	.00	139	0
03-532	F	1910		01	1926	190	1974	56	B2	0.0	Z9C	3.25	.00	215	0
03-533	F	1908		01	1925	260	1974	15	B1	0.0	Z9C	.87	.00	59	0
03-534	F	1910		01	1925	104	1959	3	C6	0.0	Z9	.15	.00	10	0
03-535	F	1907		01	1922	21	1964	227	C2	0.0	Z9	12.59	.00	899	0
03-536	F	1910		01	1925	7	1959	35	C2	0.0	Z9	1.74	.00	120	0
03-537	F	1900		07	1916	52	1972	6	B3	0.0	Z9C	.39	.00	30	0
03-538	F	1909		01	1927	13	1959	61	C2	0.0	Z9	2.94	.00	197	0
03-539	F	1900		01	1922	20	1974	5	B2	0.0	Z9C	.33	.00	24	0
03-540	F	1904		01	1923	364	1973	1605	B1	0.0	Z9C	96.17	.00	6672	0
03-541	F	1913		01	1935	156	1973	1	B6	0.0	Z9C	.03	.00	2	0
03-542	F	1904		01	1924	13	1974	24	B1	0.0	Z9C	1.47	.00	102	0
03-543	F	1918		01	1947	100	1972	1	B6	0.0	Z9C	.05	.00	2	0
03-544	F	1906	1975	01	1922	26	1959	5	C3	0.0	Z9	.26	.00	19	0
03-545	F	1898		01	1920	208	1959	0	C6	0.0	Z9	.00	.00	0	0
03-546	F	1903		01	1925	52	1959	95	C2	0.0	Z9	4.70	.00	322	0
03-547	F	1907	1962	01	1923	108	1959	19	C2	0.00370	F2	.96	.25	55	19
03-548	F	1906		01	1922	17	1971	80	B1	0.0	Z9C	4.81	.00	344	0
03-549	F	1910		01	1925	936	1974	36	B1	0.0	Z9C	2.18	.00	149	0
03-550	F	1900		01	1917	104	1972	8	B3	0.0	Z9C	.49	.00	37	0
03-551	F	1903		01	1922	338	1973	1077	C2	0.0	Z9C	64.87	.00	4530	0
03-552	F	1904		01	1924	108	1972	123	B1	0.0	Z9C	7.25	.00	500	0
03-553	F	1904		01	1924	13	1974	5	B2	0.0	Z9C	.33	.00	23	0
03-554	F	1899		01	1924	433	1961	2000	G4	0.0	Z9	102.63	.00	7074	0
03-555	F	1913		71	1930	260	1972	2	B6	0.0	Z9C	.13	.00	8	0
03-556	F	1911		01	1928	100	1973	1	B6	0.0	Z9C	.05	.00	3	0
03-557	F	1910		01	1925	3	1959	0	C6	0.0	Z9	.00	.00	0	0
03-558	F	1904	1971	01	1923	13	1959	115	C2	0.02173	C6	5.89	10.04	395	755

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
03-559	F	1907	1975	01	1922	21	1959	17	C2	0.0	Z9	.88	.00	63	0
03-561	F	1917		61	1924	416	1959	67	C2	0.0	Z9	3.34	.00	230	0
03-562	F	1908		01	1927	520	1972	4	B3	0.0	Z9C	.19	.00	12	0
03-563	F	1909		01	1924	10	1975	2	B3	0.0	Z9C	.15	.00	10	0
03-564	F	1906		01	1923	3	1972	4	B3	0.0	Z9C	.21	.00	15	0
03-565	F	1913		01	1930	676	1972	5	B3	0.0	Z9C	.27	.00	16	0
03-566	F	1910		01	1930	624	1972	1	B6	0.0	Z9C	.03	.00	2	0
03-567	F	1900		01	1922	104	1972	26	B2	0.0	Z9C	1.54	.00	109	0
03-568	F	1905		01	1922	260	1959	120	C2	0.0	Z9	6.07	.00	424	0
03-569	F	1901	1973	01	1922	312	1959	144	C2	0.0	Z9	7.28	.00	495	0
03-570	F	1908		01	1925	43	1972	4	B3	0.0	Z9C	.23	.00	16	0
03-571	F	1909		01	1925	52	1975	821	B2	0.0	Z9C	49.75	.00	3406	0
03-572	F	1906		01	1924	56	1974	75	B1	0.0	Z9C	4.55	.00	316	0
03-573	F	1900		01	1925	52	1974	14	B1	0.0	Z9C	.81	.00	56	0
03-574	F	1904		71	1920	624	1972	0	B6	0.0	Z9C	.02	.00	2	0
03-575	F	1913		01	1931	52	1973	0	B6	0.0	Z9C	.00	.00	0	0
03-576	F	1909		01	1925	156	1972	6	B3	0.0	Z9C	.35	.00	24	0
03-577	F	1903	1961	01	1921	104	1959	81	C2	0.0	Z9	4.22	.00	247	0
03-578	F	1909		01	1925	30	1959	17	C2	0.0	Z9	.84	.00	58	0
03-579	F	1905		01	1922	13	1959	30	C2	0.0	Z9	1.56	.00	111	0
03-580	F	1904		01	1923	4	1959	2	C6	0.0	Z9	.10	.00	7	0
03-581	F	1904		01	1922	10	1959	13	C3	0.0	Z9	.68	.00	48	0
03-583	M	1893	1962	07	1930	+0	1959	50	C2	0.0	Z9	1.64	.00	84	0
03-584	F	1905	1959	01	1923	+0	1959	6000	A4	0.0	Z9	307.93	.00	17131	0
03-585	F	1894		01	1918	260	1966	74	C2	0.0	Z9	4.29	.00	313	0
03-586	F	1908	1968	01	1926	82	1967	900	C2	0.0	Z9	48.92	.00	2972	0
03-587	F	1906		01	1925	34	1959	13	C3	0.0	Z9	.64	.00	44	0
03-588	F	1901	1967	01	1922	229	1962	316	C2	0.0	Z9	16.67	.00	1041	0
03-589	F	1906	1969	01	1924	21	1959	77	C2	0.0	Z9	3.88	.00	249	0
03-590	F	1900		01	1922	26	1965	104	C2	0.0	Z9	5.84	.00	417	0
03-591	F	1907		61	1926	2340	1972	6	B3	0.0	Z9C	.19	.00	8	0
03-592	F	1905		01	1922	78	1966	123	C2	0.0	Z9	6.94	.00	493	0
03-593	F	1905		01	1922	4	1974	11	C3	0.0	Z9C	.68	.00	48	0
03-594	F	1905	1968	01	1922	52	1959	41	C2	0.0	Z9	2.12	.00	137	0
03-595	F	1902		01	1927	52	1975	1	B6	0.0	Z9C	.06	.00	4	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
03-596	F	1904		01	1922	8	1975	12	B2	0.0	Z9C	.73	.00	52	0
03-597	F	1903		16	1925	1300	1972	74	B1	0.0	Z9C	3.66	.00	208	0
03-598	M	1890		07	1933	4	1971	1	B6	0.0	Z9C	.03	.00	2	0
03-599	F	1906	1975	01	1922	26	1959	9	C3	0.0	Z9	.47	.00	33	0
03-600	F	1902		07	1926	988	1972	0	B6	0.0	Z9C	.00	.00	0	0
03-601	F	1893	1969	01	1925	260	1960	6	C3	0.0	Z9	.30	.00	19	0
03-602	F	1899		01	1925	104	1960	3	C6	0.0	Z9	.15	.00	10	0
03-603	F	1888		01	1924	520	1960	0	C6	0.0	Z9	.00	.00	0	0
03-604	F	1899		01	1916	624	1971	4	B3	0.0	Z9C	.27	.00	19	0
03-605	F	1900		01	1921	364	1972	1	B6	0.0	Z9C	.04	.00	3	0
03-606	F	1903		01	1924	6	1971	2	B6	0.0	Z9C	.11	.00	8	0
03-607	F	1906		01	1922	26	1974	124	B2	0.0	Z9C	7.68	.00	548	0
03-608	F	1901		01	1919	104	1960	19	C2	0.0	Z9	1.03	.00	76	0
03-609	F	1896	1974	01	1923	4	1960	0	C6	0.0	Z9	.00	.00	0	0
03-610	F	1917		01	1935	104	1973	1	B6	0.0	Z9C	.07	.00	4	0
03-611	F	1893	1969	01	1916	208	1960	3	C6	0.0	Z9	.17	.00	12	0
03-612	F	1892	1968	01	1918	234	1960	500	C2	0.0	Z9	27.01	.00	1806	0
03-613	F	1905		01	1925	95	1972	2	B6	0.0	Z9C	.09	.00	6	0
03-614	F	1909		01	1924	56	1975	94	B2	0.0	Z9	5.74	.00	398	0
03-615	F	1905		01	1923	107	1975	14	B1	0.0	Z9	.88	.00	61	0
03-617	F	1902	1951	01	1921	312	1963	7000	F4	0.0	Z9	311.96	.00	14586	0
03-618	F	1893	1969	01	1920	43	1960	10	C3	0.0	Z9	.54	.00	36	0
03-619	F	1903	1962	01	1922	34	1962	1576	C3	0.00144	F1	85.07	15.23	5041	1143
03-620	F	1923		01	1942	208	1971	5	B3	0.0	Z9C	.21	.00	11	0
03-621	F	1916		01	1944	208	1971	4	B3	0.0	Z9C	.17	.00	8	0
03-622	F	1910		01	1926	104	1960	0	G6	0.0	Z9	.00	.00	0	0
03-623	F	1902		01	1924	+0	1963	4	G6	0.0	Z9	.21	.00	15	0
03-624	F	1905	1959	01	1923	156	1959	1000	A4	0.0	Z9	50.19	.00	2716	0
03-625	F	1901		01	1923	13	1972	0	B6	0.0	Z9C	.01	.00	0	0
03-626	F	1906		01	1924	208	1960	200	G4	0.0	Z9	10.11	.00	697	0
03-627	F	1905	1966	01	1924	208	1960	50	G4	0.0	Z9	2.53	.00	153	0
03-628	F	1905	1974	01	1921	34	1962	0	C6	0.0	Z9	.00	.00	0	0
03-629	F	1904	1969	01	1922	+0	1960	0	G6	0.0	Z9	.00	.00	0	0
03-630	F	1908		01	1924	17	1974	19	B1	0.0	Z9C	1.12	.00	78	0
03-632	F	1905	1975	01	1922	0	1960*	0	G6	0.0	Z9	.00	.00	0	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
03-633	F	1902		01	1922	780	1960*	0	G6	0.0	Z9	.00	.00	0	0
03-634	F	1909	1961	01	1924	+0	1960	3	G6	0.0	Z9	.15	.00	9	0
03-635	F	1907		01	1925	+0	1960	47	G6	0.0	Z9	2.38	.00	164	0
03-636	F	1904		01	1926	208	1973	8	B2	0.0	Z9C	.44	.00	29	0
03-637	F	1906		01	1924	6	1972	43	B2	0.0	Z9C	2.58	.00	180	0
03-638	F	1902	1972	01	1924	+0	1960	7	G6	0.0	Z9	.36	.00	24	0
03-639	F	1912		01	1925	156	1960	67	G4	0.0	Z9	3.36	.00	230	0
03-640	F	1902		01	1924	60	1960	5	C3	0.0	Z9	.25	.00	18	0
03-641	F	1904		01	1922	26	1973	11	B2	0.0	Z9C	.68	.00	49	0
03-642	F	1905		01	1922	52	1972	34	B2	0.0	Z9C	2.05	.00	146	0
03-643	F	1909		01	1926	156	1975	10	B2	0.0	Z9C	.57	.00	38	0
03-645	F	1906		01	1924	312	1959	56	C2	0.0	Z9	2.79	.00	192	0
03-646	F	1888		01	1926	0	1960*	20	G6	0.0	Z9	1.00	.00	68	0
03-647	F	1901		01	1925	5	1960	35	G6	0.0	Z9	1.77	.00	122	0
03-648	F	1903	1956	01	1922	155	1955	5000	B2	0.00430	F2	243.29	54.14	12670	4043
03-649	F	1906	1954	01	1924	1352	1951	1300	B2	0.0	Z9F	56.32	.00	2725	0
03-671	F	1906	1953	01	1922	8	1952	3820	B2	0.00500	F1	178.08	33.88	8980	2525
03-672	F	1899		01	1924	+0	1960	3	G6	0.0	Z9	.15	.00	11	0
03-673	F	1909		71	1926	8	1960	35	G6	0.0	Z9	1.74	.00	118	0
03-674	F	1908		01	1925	43	1960	9	C3	0.0	Z9	.45	.00	31	0
03-676	F	1906		01	1924	+0	1963	1700	C2	0.0	Z9	90.96	.00	6351	0
03-677	M	1899	1965	06	1924	+0	1963	232	G4	0.0	Z9	8.63	.00	522	0
03-678	M	1919		71	1953	988	1972	6	B3	0.0	Z9C	.08	.00	2	0
03-679	F	1910		01	1930	10	1972	1	B6	0.0	Z9C	.07	.00	5	0
03-681	F	1906		01	1922	6	1962	1	G6	0.0	Z9	.03	.00	2	0
03-682	F	1907		01	1925	60	1973	1	B6	0.0	Z9C	.07	.00	4	0
03-683	F	1906		01	1923	0	1961	0	C6	0.0	Z9	.00	.00	0	0
03-684	F	1907		01	1927	17	1972	1	B6	0.0	Z9C	.06	.00	4	0
03-685	F	1902		01	1921	65	1974	84	B1	0.0	Z9C	5.25	.00	378	0
03-686	F	1904		01	1923	1040	1975	20	B2	0.0	Z9C	1.20	.00	83	0
03-687	F	1900	1974	01	1925	43	1961	51	C2	0.0	Z9	2.60	.00	176	0
03-688	F	1918		01	1936	260	1972	3	B6	0.0	Z9C	.12	.00	7	0
03-689	F	1903		01	1923	208	1961	130	C2	0.0	Z9	6.72	.00	466	0
03-690	F	1909	1967	01	1924	290	1958	320	C2	0.0	Z9	15.69	.00	965	0
03-692	M	1887		07	1920	+0	1961	5	C3	0.0	Z9	.24	.00	17	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
03-693	F	1920		01	1942	520	1952	14	G6	0.0	Z9	.18	.00	8	0
03-695	F	1920		01	1942	34	1972	7	B3	0.0	Z9C	.33	.00	17	0
03-696	F	1932		01	1950	52	1963	0	C6	0.0	Z9	.00	.00	0	0
03-697	F	1902		01	1924	34	1967	181	C2	0.0	Z9	10.15	.00	706	0
03-703	F	1921		01	1946	416	1974	0	B6	0.0	Z9C	.01	.00	1	0
03-713	F	1921		01	1941	1456	1971	2	B6	0.0	Z9C	.05	.00	2	0
03-714	F	1923		01	1942	364	1971	3	B3	0.0	Z9C	.15	.00	7	0
03-716	F	1920		01	1941	104	1971	0	B6	0.0	Z9C	.00	.00	0	0
03-720	F	1910		01	1926	52	1973	2	B6	0.0	Z9C	.13	.00	9	0
03-722	F	1905		01	1924	26	1972	2	B6	0.0	Z9C	.09	.00	6	0
03-726	F	1905	1972	01	1922	186	1968	574	C2	0.0	Z9	32.77	.00	2206	0
03-727	F	1906		01	1923	988	1972	165	B1	0.0	Z9B	9.78	.00	678	0
03-729	F	1926		01	1943	208	1973	1	B6	0.0	Z9C	.05	.00	3	0
03-730	M	1894	1963	06	1923	+0	1961	7	C3	0.0	Z9	.26	.00	16	0
03-732	F	1924		01	1942	78	1973	2	B6	0.0	Z9C	.07	.00	4	0
03-736	F	1895		16	1919	22	1975*	1	B6	0.0	Z9C	.03	.00	2	0
03-741	F	1908		01	1925	260	1975	4	B3	0.0	Z9C	.22	.00	15	0
03-752	F	1904		01	1922	15	1972	7	B3	0.0	Z9C	.41	.00	30	0
03-753	F	1906		01	1922	+0	1974	12	B2	0.0	Z9C	.75	.00	53	0
03-757	F	1902		01	1923	91	1974	14	B2	0.0	Z9C	.83	.00	58	0
03-761	F	1901		01	1927	1144	1974	19	B2	0.0	Z9C	.97	.00	55	0
03-763	F	1901		01	1930	52	1972	0	B6	0.0	Z9C	.00	.00	0	0
03-764	F	1908		01	1926	364	1973	1	B6	0.0	Z9C	.06	.00	4	0
03-774	F	1909		01	1924	3	1972	1	C6	0.0	Z9C	.05	.00	3	0
03-775	F	1922		01	1942	52	1974	4	B3	0.0	Z9C	.18	.00	9	0
03-778	F	1904		01	1923	104	1973	54	B1	0.0	Z9C	3.28	.00	229	0
03-782	F	1908		01	1923	5	1973	1	B6	0.0	Z9C	.05	.00	3	0
03-784	F	1905		01	1923	+0	1954	750	C4	0.0	Z9	35.61	.00	2519	0
03-788	F	1905		01	1926	104	1972	5	B3	0.0	Z9C	.28	.00	19	0
03-795	F	1897	1944	01	1926	78	1944	8	G6	0.0	Z9	.28	.00	10	0
03-796	F	1907		01	1925	+0	1972	0	B6	0.0	Z9C	.01	.00	1	0
03-801	F	1906		01	1924	13	1972	1	B6	0.0	Z9C	.05	.00	3	0
03-807	F	1923		01	1954	780	1973	0	B6	0.0	Z9C	.01	.00	0	0
03-810	F	1919		01	1934	312	1972	2	B6	0.0	Z9C	.09	.00	5	0
03-817	F	1907		01	1926	13	1973	0	B6	0.0	Z9C	.02	.00	2	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
03-818	F	1902		01	1927	62	1975*	4	B3	0.0	Z9C	.24	.00	16	0
03-825	F	1906		01	1922	4	1972	0	B6	0.0	Z9C	.00	.00	0	0
03-828	M	1915		17	1950	936	1972	0	B6	0.0	Z9C	.00	.00	0	0
03-834	F	1907		01	1925	+0	1972	1	B6	0.0	Z9C	.04	.00	3	0
03-836	F	1908		01	1924	23	1967	0	C6	0.0	Z9	.00	.00	0	0
03-838	F	1928		01	1947	130	1975	2	B3	0.0	Z9C	.11	.00	5	0
03-842	F	1910		01	1926	416	1973	6	B3	0.0	Z9C	.34	.00	22	0
03-845	F	1908		01	1925	104	1974	0	B6	0.0	Z9C	.01	.00	1	0
03-850	F	1923		01	1942	78	1972	19	B2	0.0	Z9C	.85	.00	44	0
05-001	F	1900		01	1919	52	1975	45	B1	0.00056	Z7B	2.89	1.37	213	103
05-002	F	1903	1973	01	1917	104	1971	1	B6	0.0	Z9B	.06	.00	5	0
05-003	F	1900	1959	01	1917	8	1958	0	G6	0.0	Z9	.00	.00	0	0
05-004	F	1904		01	1920	104	1959	12	G6	0.01600	Z7	.63	1.03	46	77
05-005	F	1901		01	1916	13	1960	0	G6	0.0	Z9	.00	.00	0	0
05-007	F	1896		01	1920	95	1967	23	B2	0.00600	Z7B	1.34	2.18	97	164
05-008	M	1894	1964	07	1916	104	1953	4	CL	0.0	Z9C	.17	.00	11	0
05-010	F	1901	1974	01	1921	34	1951	4	CL	0.01200	Z7C	.22	.32	15	24
05-011	F	1902		01	1917	52	1959	12	G6	0.0	Z9	.66	.00	50	0
05-012	F	1901	1959	01	1917	52	1970	16	A1	0.0	Z9A	.88	.00	54	0
05-014	F	1900		01	1916	208	1975	140	B1	0.00106	B6	9.12	9.77	685	735
05-015	F	1891		01	1916	67	1970	1	B6	0.0	Z9B	.06	.00	5	0
05-016	M	1891	1965	06	1916	100	1958	15	G4	0.0	Z9	.59	.00	40	0
05-017	F	1894		01	1919	+0	1968	5	G6	0.00520	Z7	.30	.61	22	46
05-018	M	1886		06	1918	156	1971	4	B3	0.00180	Z7B	.18	.17	13	12
05-019	F	1885	1968	01	1921	2	1960	0	G6	0.01400	Z7	.00	.00	0	0
05-020	F	1898		01	1917	52	1959	3	G6	0.0	Z9	.17	.00	13	0
05-022	F	1900	1969	07	1916	32	1964	4	CL	0.0	Z9C	.24	.00	17	0
05-023	F	1899	1960	01	1913	104	1960	38	C2	0.00320	Z7C	2.09	.97	126	73
05-024	M	1890	1965	06	1916	208	1961	4	CL	0.01200	Z7C	.16	.36	11	27
05-025	F	1893		01	1917	78	1971	86	B1	0.00020	Z7B	5.41	.70	408	53
05-037	F	1898		01	1916	260	1971	0	B6	0.0	Z9B	.00	.00	0	0
05-038	F	1901		07	1915	156	1972	99	G4	0.0	Z9	6.30	.00	476	0
05-039	F	1899		01	1917	156	1975	19	B2	0.00078	Z7B	1.23	.93	92	70
05-040	F	1899		01	1917	54	1971	10	B2	0.0	Z9B	.63	.00	48	0
05-042	F	1918		01	1940	130	1972	1	B6	0.0	Z9B	.05	.00	3	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
05-043	M	1888	1960	06	1919	208	1965	0	F6	0.00430	Z7F	.00	.00	0	0
05-044	M	1895	1975	06	1915	468	1971	2	B6	0.0	Z9B	.09	.00	7	0
05-045	F	1899	1960	01	1917	60	1965	5	F4	0.0	Z9F	.28	.00	17	0
05-049	F	1905		01	1923	13	1965	6	C3	0.0	Z9C	.33	.00	24	0
05-088	F	1886		01	1917	4	1959	4	G6	0.0	Z9	.22	.00	17	0
05-089	F	1900		01	1916	78	1971	13	B2	0.0	Z9B	.83	.00	63	0
05-092	F	1901		01	1916	104	1959	6	G6	0.0	Z9	.33	.00	25	0
05-093	F	1897	1974	71	1915	78	1961	6	C6	0.0	Z9C	.35	.00	26	0
05-094	F	1927		01	1946	39	1973	6	B3	0.0	Z9B	.26	.00	13	0
05-096	F	1901	1971	01	1918	26	1962	234	C2	0.00050	Z7C	13.29	1.36	949	102
05-097	M	1892		06	1918	26	1961	4	CL	0.00050	Z7C	.16	.01	12	1
05-100	F	1907		01	1919	156	1968	4	G6	0.00520	Z7	.24	.40	17	30
05-101	F	1902		01	1924	6	1964	4	CL	0.00850	Z7C	.22	.24	15	18
05-102	F	1900		01	1915	364	1960	6	C6	0.00350	Z7C	.33	.17	25	13
05-103	F	1906		01	1923	4	1959	1	G6	0.01600	Z7	.05	.07	4	5
05-104	F	1900		01	1918	13	1964	4	CL	0.00040	Z7C	.23	.02	17	2
05-105	M	1903	1959	07	1918	30	1959	0	G6	0.00070	Z7	.00	.00	0	0
05-116	F	1898	1959	01	1917	52	1972	19	A1	0.0	Z9A	1.05	.00	64	0
05-117	M	1887	1968	06	1915	208	1964	4	CL	0.0	Z9C	.17	.00	12	0
05-118	F	1901		01	1917	65	1972	5	B3	0.0	Z9B	.32	.00	24	0
05-119	F	1905		01	1924	212	1974	16	B2	0.00252	Z7	.96	.94	66	70
05-120	F	1890		07	1919	6	1959	5	G6	0.00770	Z7	.27	.27	20	20
05-121	F	1906		01	1921	26	1970	9	B2	0.00390	Z7B	.54	.79	39	60
05-122	M	1879	1962	07	1922	208	1959	11	G6	0.01600	Z7	.40	.44	23	33
05-123	F	1897	1972	01	1918	1	1960	4	G6	0.00060	Z7	.22	.02	16	2
05-125	F	1902		07	1916	104	1959	26	G4	0.0	Z9	1.45	.00	110	0
05-126	M	1889	1970	01	1921	52	1970	0	B6	0.0	Z9B	.00	.00	0	0
05-127	M	1893		06	1918	999	1967	20	B2	0.0	Z9B	.76	.00	51	0
05-129	F	1900	1969	07	1917	104	1960	4	CL	0.0	Z9C	.22	.00	16	0
05-130	F	1920		01	1940	78	1972	0	B6	0.0	Z9B	.00	.00	0	0
05-132	F	1898		07	1918	52	1969	0	G6	0.00020	Z7	.00	.00	0	0
05-133	M	1903	1967	07	1918	13	1959	0	G6	0.00070	Z7	.00	.00	0	0
05-134	F	1900		01	1917	6	1959	9	G6	0.0	Z9	.50	.00	38	0
05-135	F	1919		01	1941	104	1972	2	B6	0.0	Z9C	.09	.00	5	0
05-136	M	1896	1966	06	1917	78	1959	94	G4	0.0	Z9	3.70	.00	249	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
05-138	F	1917		01	1941	104	1968	5	B3	0.0	Z93	.22	.00	11	0
05-139	F	1891	1966	01	1919	70	1962	4	CL	0.00540	Z7C	.22	.21	15	16
05-140	F	1897	1960	01	1916	+0	1965	490	F4	0.0	Z9F	27.91	.00	1770	0
05-142	F	1904		01	1919	39	1960	11	G6	0.00680	Z7	.60	.57	44	43
05-143	F	1899	1962	07	1918	+0	1961	4	CL	0.0	Z9C	.23	.00	14	0
05-145	M	1883	1961	07	1916	572	1961	4	CL	0.00150	Z7C	.15	.03	9	2
05-146	M	1897		06	1920	286	1968	2	G6	0.00490	Z7	.08	.10	6	7
05-150	F	1899	1969	07	1917	6	1960	45	G6	0.0	Z9	2.53	.00	179	0
05-151	F	1897		01	1924	95	1963	7	C3	0.00960	Z7C	.37	.36	26	27
05-154	F	1900		01	1916	11	1970	0	G6	0.0	Z9	.00	.00	0	0
05-155	F	1898	1965	07	1916	28	1963	4	CL	0.0	Z9C	.24	.00	16	0
05-160	F	1917		01	1942	156	1969	0	G6	0.0	Z9	.00	.00	0	0
05-161	M	1901		06	1918	9	1971	0	B6	0.0	Z9B	.00	.00	0	0
05-162	F	1914		07	1942	+0	1960	29	G6	0.0	Z9	1.04	.00	55	0
05-163	M	1912	1970	07	1941	104	1960	35	G6	0.0	Z9	.89	.00	42	0
05-165	F	1899	1964	01	1919	13	1972	1	A6	0.00140	Z7A	.05	.04	3	3
05-172	F	1907	1960	01	1934	999	1960	24	G4	0.0	Z9	.78	.00	26	0
05-174	F	1902		01	1919	130	1969	11	G6	0.00330	Z7	.66	.82	48	61
05-179	F	1921		01	1940	182	1974	0	B6	0.0	Z9B	.00	.00	0	0
05-181	F	1901		01	1918	4	1970	0	B6	0.0	Z9B	.00	.00	0	0
05-184	M	1900	1974	41	1922	156	1964	5	C6	0.0	Z9C	.19	.00	14	0
05-185	F	1912		01	1941	208	1972	2	B6	0.0	Z9B	.09	.00	5	0
05-186	F	1922		01	1941	156	1972	1	B6	0.0	Z9B	.05	.00	2	0
05-188	M	1889	1964	07	1917	104	1961	4	CL	0.0	Z9C	.16	.00	10	0
05-189	M	1890	1972	07	1921	104	1964	4	CL	0.00850	Z7C	.16	.22	11	17
05-197	M	1898		07	1919	7	1973	0	B6	0.00140	Z7B	.00	.00	0	0
05-199	F	1901		16	1917	2	1967	0	B6	0.0	Z9B	.00	.00	0	0
05-201	F	1919		01	1941	221	1972	5	B3	0.0	Z9B	.23	.00	12	0
05-203	F	1899		01	1919	52	1960	0	G6	0.00680	Z7	.00	.00	0	0
05-204	M	1880	1961	07	1918	73	1960	0	G6	0.00320	Z7	.00	.00	0	0
05-205	F	1907		01	1924	208	1961	4	CL	0.0	Z9C	.21	.00	14	0
05-206	F	1894		01	1922	52	1971	2	B6	0.00360	Z7B	.12	.16	9	12
05-207	M	1893		06	1917	+0	1962	6	G6	0.0	Z9	.25	.00	19	0
05-210	F	1899	1971	01	1916	158	1964	20	G6	0.0	Z9	1.17	.00	84	0
05-212	F	1903		07	1918	8	1965	4	CL	0.00030	Z7C	.24	.02	18	2

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
05-215	F	1886	1968	01	1917	52	1969	1410	A1	0.00198	A3	86.29	89.56	5986	6734
05-237	M	1896	1969	06	1920	364	1961	4	CL	0.0	Z9C	.15	.00	10	0
05-246	F	1884	1969	06	1911	728	1962	4	CL	0.0	Z9C	.23	.00	16	0
05-251	F	1896		01	1917	34	1965	13	G4	0.0	Z9	.77	.00	58	0
05-252	F	1890		01	1917	52	1964	4	CL	0.0	Z9C	.23	.00	18	0
05-255	M	1886	1966	07	1920	104	1964	5	C6	0.00850	Z7C	.20	.32	13	24
05-257	F	1895	1975	01	1932	1248	1972	3	G6	0.0	Z9	.13	.00	7	0
05-258	F	1901		01	1917	1	1970	0	G6	0.0	Z9	.00	.00	0	0
05-259	F	1900		07	1917	52	1960	6	G6	0.0	Z9	.34	.00	25	0
05-260	F	1898		07	1917	32	1960	0	G6	0.0	Z9	.00	.00	0	0
05-261	F	1892		01	1943	104	1960	4	CL	0.0	Z9C	.13	.00	7	0
05-262	F	1917		01	1942	260	1972	3	B3	0.0	Z9C	.13	.00	7	0
05-263	M	1883	1967	07	1919	104	1962	4	CL	0.00800	Z7C	.16	.21	11	16
05-264	M	1903		07	1917	5	1961	4	CL	0.0	Z9C	.16	.00	12	0
05-265	M	1884	1963	07	1916	104	1962	4	CL	0.0	Z9C	.16	.00	11	0
05-266	M	1881	1970	07	1918	130	1964	4	CL	0.00200	Z7C	.16	.08	11	6
05-268	F	1893		01	1918	39	1960	4	CL	0.00060	Z7C	.22	.02	17	2
05-269	M	1887	1971	07	1918	52	1964	4	CL	0.00040	Z7C	.17	.02	12	1
05-270	M	1901		07	1916	52	1961	8	C3	0.0	Z9C	.33	.00	25	0
05-272	M	1895		06	1918	65	1972	0	B6	0.0	Z9B	.00	.00	0	0
05-273	F	1889	1968	01	1918	104	1960	4	CL	0.01400	Z7C	.22	.45	15	34
05-274	F	1903		07	1920	4	1970	0	G6	0.0	Z9	.00	.00	0	0
05-276	F	1906		01	1921	75	1961	4	CL	0.01200	Z7C	.21	.31	15	23
05-277	M	1894	1973	06	1918	104	1960	4	CL	0.00320	Z7C	.16	.07	11	6
05-278	F	1893	1965	01	1917	52	1965	44	G4	0.0	Z9	2.61	.00	174	0
05-279	F	1896		01	1917	1820	1969	0	G6	0.0	Z9	.00	.00	0	0
05-281	F	1898	1964	01	1916	148	1962	720	B1	0.00250	F1	41.29	23.20	2717	1743
05-282	F	1898		01	1917	34	1964	8	C6	0.0	Z9C	.47	.00	36	0
05-284	F	1899	1973	01	1919	156	1969	218	B1	0.00080	Z7B	13.06	3.78	930	284
05-286	M	1901	1963	06	1916	104	1965	0	F4	0.0	Z9F	.00	.00	0	0
05-287	M	1889	1970	07	1917	390	1965	4	CL	0.00420	Z7C	.16	.14	11	11
05-288	F	1897		01	1918	10	1960	4	CL	0.00060	Z7C	.22	.02	17	2
05-290	F	1898	1967	01	1918	52	1960	8	C3	0.0	Z9C	.44	.00	30	0
05-291	F	1902	1974	01	1920	8	1968	4	G6	0.00540	Z7	.24	.44	17	33
05-292	M	1904	1974	07	1918	+0	1965	4	CL	0.0	Z9C	.17	.00	13	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
05-304	F	1897		01	1921	26	1962	4	CL	0.01100	Z7C	.22	.34	16	26
05-306	F	1903		01	1921	156	1973	5	B3	0.00280	Z7B	.31	.40	22	30
05-307	F	1920		01	1944	74	1972	0	B6	0.0	Z9B	.00	.00	0	0
05-308	M	1893	1964	07	1916	208	1962	4	CL	0.00130	Z7C	.16	.04	11	3
05-310	F	1894	1965	01	1916	78	1964	5	C6	0.0	Z9C	.30	.00	20	0
05-311	M	1887	1961	06	1920	156	1960	4	CL	0.01400	Z7C	.15	.23	9	17
05-312	M	1886	1961	01	1919	34	1961	2	F6	0.00610	Z7F	.08	.08	5	6
05-318	M	1901	1961	07	1918	+0	1965	4	F4	0.00030	Z7F	.16	.01	10	1
05-321	F	1899		01	1916	208	1966	16	G6	0.00330	Z7	.95	1.07	72	80
05-322	M	1900	1975	07	1917	312	1973	4	B3	0.00070	Z7B	.18	.08	13	6
05-323	F	1899	1961	01	1915	26	1961	4	CL	0.0	Z9C	.23	.00	15	0
05-351	F	1891		01	1917	30	1968	23	G6	0.00030	Z7	1.41	.20	107	15
05-352	M	1900	1963	07	1917	40	1964	1	F6	0.0	Z9F	.04	.00	3	0
05-353	M	1900		07	1915	13	1973	1	B6	0.0	Z9B	.05	.00	4	0
05-357	F	1890		07	1917	104	1972	3	G6	0.0	Z9	.19	.00	14	0
05-360	M	1892	1968	01	1914	+0	1963	4	CL	0.0	Z9C	.17	.00	12	0
05-363	F	1899		07	1917	9	1964	4	CL	0.0	Z9C	.24	.00	18	0
05-368	F	1901		07	1917	104	1972	1	B6	0.0	Z9C	.06	.00	5	0
05-369	F	1901		07	1919	26	1973	1	B6	0.00140	Z7B	.06	.06	5	5
05-370	F	1895		01	1920	26	1965	4	CL	0.00760	Z7C	.23	.40	17	30
05-372	F	1888	1970	01	1916	104	1968	14	G4	0.0	Z9	.86	.00	62	0
05-374	F	1905		01	1923	8	1964	4	CL	0.00850	Z7C	.22	.27	16	20
05-377	F	1895	1974	01	1916	15	1969	0	G6	0.0	Z9	.00	.00	0	0
05-380	F	1904	1970	07	1925	104	1962	4	CL	0.01100	Z7C	.21	.18	13	13
05-383	F	1901		06	1917	165	1973	73	B1	0.00060	Z7B	4.64	2.07	346	156
05-387	M	1902		06	1918	9	1975	0	B6	0.0	Z9B	.00	.00	0	0
05-395	F	1911		01	1928	728	1970	10	G6	0.0	Z9	.50	.00	30	0
05-397	F	1900		07	1918	13	1962	4	CL	0.0	Z9C	.23	.00	17	0
05-399	M	1892		07	1916	104	1961	4	CL	0.0	Z9C	.16	.00	12	0
05-401	M	1898		76	1917	169	1971	5	B3	0.00170	Z7B	.22	.22	17	16
05-407	F	1898		01	1916	9	1973	1	B6	0.0	Z9B	.07	.00	5	0
05-409	F	1900		07	1918	61	1974	0	B6	0.0	Z9B	.00	.00	0	0
05-410	F	1899		01	1916	26	1971	2	B6	0.0	Z9B	.13	.00	10	0
05-413	F	1900	1971	01	1916	39	1969	18	B2	0.0	Z9B	1.13	.00	82	0
05-420	F	1888	1935	01	1917	104	1970	50	A1	0.0	Z9A	1.74	.00	60	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
05-437	F	1883		07	1923	26	1971	3	B3	0.0	Z9B	.18	.00	13	0
05-438	F	1907		01	1926	13	1961	4	CL	0.0	Z9C	.20	.00	14	0
05-439	F	1898	1970	01	1916	104	1967	200	G6	0.0	Z9	12.18	.00	872	0
05-440	F	1896	1975	01	1922	1	1971	0	B6	0.0	Z9B	.00	.00	0	0
05-442	F	1888		07	1917	6	1962	8	G6	0.0	Z9	.46	.00	35	0
05-443	F	1922		07	1941	52	1972	3	B6	0.0	Z9B	.14	.00	8	0
05-444	M	1899	1963	06	1917	43	1961	4	CL	0.0	Z9C	.16	.00	11	0
05-446	M	1888	1971	45	1925	+0	1964	4	CL	0.0	Z9C	.15	.00	10	0
05-447	F	1902		01	1916	9	1970	2	B6	0.0	Z9B	.13	.00	10	0
05-448	F	1903		01	1916	1	1961	4	CL	0.0	Z9C	.23	.00	18	0
05-449	F	1892	1961	01	1919	52	1961	4	CL	0.00610	Z7C	.22	.21	13	16
05-450	F	1903		07	1918	117	1971	1	B6	0.00090	Z7B	.06	.03	5	2
05-459	F	1917		01	1933	208	1961	8	C6	0.0	Z9C	.35	.00	21	0
05-460	F	1898		07	1916	182	1961	4	CL	0.00150	Z7C	.23	.06	17	5
05-464	F	1895	1969	01	1917	+0	1968	5	G6	0.0	Z9	.31	.00	22	0
05-473	M	1899	1970	06	1921	26	1962	4	CL	0.01100	Z7C	.16	.24	11	18
05-528	F	1892		01	1917	52	1967	0	G6	0.0	Z9	.00	.00	0	0
05-541	F	1913		01	1937	884	1972	0	B6	0.0	Z9B	.00	.00	0	0
05-546	F	1902		06	1918	52	1973	1	B6	0.0	Z9B	.06	.00	5	0
05-551	F	1895		01	1918	9	1970	15	G6	0.0	Z9	.93	.00	70	0
05-555	F	1899	1965	07	1917	27	1975*	1	A6	0.0	Z9	.06	.00	4	0
05-560	M	1894	1965	07	1921	260	1962	4	CL	0.01100	Z7C	.15	.18	9	13
05-580	M	1904		07	1919	6	1968	4	G6	0.00260	Z7	.17	.17	13	13
05-602	M	1899		06	1925	1300	1975*	0	B6	0.0	Z9B	.00	.00	0	0
05-611	F	1900	1938	01	1914	156	1974	0	A6	0.0	Z9A	.00	.00	0	0
05-631	F	1897		01	1917	17	1970	0	G6	0.0	Z9	.00	.00	0	0
05-639	M	1906	1962	06	1922	39	1964	1	F6	0.00850	Z7F	.04	.05	2	4
05-674	M	1922		06	1946	156	1965	4	CL	0.0	Z9C	.10	.00	5	0
05-742	F	1898		01	1916	30	1969	0	G6	0.0	Z9	.00	.00	0	0
05-751	F	1901	1933	01	1920	+0	1969	0	A6	0.00500	Z7A	.00	.00	0	0
05-765	F	1900		07	1916	117	1964	4	CL	0.0	Z9C	.24	.00	18	0
05-802	F	1893		01	1918	+0	1972	1	B6	0.0	Z9B	.03	.00	2	0
05-818	F	1901	1969	01	1918	52	1967	25	B2	0.0	Z9B	1.50	.00	104	0
05-873	F	1894		07	1917	286	1962	39	C2	0.00350	Z7C	2.17	1.27	160	95
05-880	F	1921		01	1939	520	1974	2	B6	0.0	Z9B	.09	.00	5	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
05-882	F	1917	1965	01	1935	468	1964	13	G6	0.0	Z9	.54	.00	24	0
05-885	F	1917		01	1939	572	1969	0	G6	0.0	Z9	.00	.00	0	0
05-892	F	1904		01	1917	4	1968	70	G6	0.0	Z9	4.30	.00	327	0
05-897	F	1899	1968	01	1917	69	1968	1310	G4	0.00030	Z7	80.03	10.92	5541	821
05-898	F	1919		01	1936	468	1972	0	B6	0.0	Z9B	.00	.00	0	0
05-900	F	1919	1973	01	1936	312	1972	3	B3	0.0	Z9C	.15	.00	8	0
05-901	F	1918		01	1934	468	1972	2	B6	0.0	Z9B	.10	.00	6	0
05-902	F	1919		01	1936	988	1962	6	C6	0.0	Z9C	.20	.00	10	0
05-905	F	1916		76	1937	156	1972	0	B6	0.0	Z9B	.00	.00	0	0
05-906	F	1913		01	1935	624	1972	2	B6	0.0	Z9B	.09	.00	5	0
05-907	F	1915		01	1935	260	1972	3	B6	0.0	Z9C	.15	.00	9	0
05-911	M	1886		07	1923	6	1972	0	G6	0.0	Z9	.00	.00	0	0
05-912	M	1877	1951	07	1918	26	1959	0	A6	0.0	Z9A	.00	.00	0	0
05-917	F	1902		01	1918	39	1966	83	B1	0.00030	Z7C	4.93	.48	368	36
05-920	M	1895	1963	06	1917	43	1962	4	CL	0.00050	Z7C	.16	.02	11	1
05-921	F	1896		01	1916	30	1969	67	G4	0.0	Z9	4.19	.00	321	0
05-942	M	1901		06	1918	9	1975	0	B6	0.0	Z9B	.00	.00	0	0
05-949	M	1899	1974	06	1921	422	1968	0	G6	0.0	Z9	.00	.00	0	0
05-962	F	1894		01	1918	84	1964	47	C2	0.00200	Z7C	2.71	1.32	202	99
05-974	F	1900		07	1918	104	1970	0	G6	0.00100	Z7	.00	.00	0	0
05-979	F	1897		01	1917	4	1969	194	G4	0.0	Z9	12.05	.00	915	0
05-985	F	1921		01	1939	130	1965	5	C6	0.0	Z9C	.21	.00	11	0
05-993	M	1902	1972	07	1917	6	1971	7	B3	0.0	Z9B	.32	.00	23	0
05-994	F	1886		01	1922	26	1967	9	G4	0.00570	Z7	.52	.68	37	51
05-998	F	1902		01	1918	3	1974	0	B6	0.0	Z9B	.00	.00	0	0
09-001	F	1901		01	1917	39	1971	4	B3	0.0	Z9B	.25	.00	19	0
09-002	F	1902	1970	01	1917	17	1959	28	C2	0.0	Z9C	1.55	.00	111	0
09-003	M	1892	1963	06	1914	572	1959	410	B1	0.0	Z9B	15.73	.00	989	0
09-004	F	1890	1961	01	1912	416	1960	550	C2	0.0	Z9C	31.30	.00	2013	0
09-006	F	1898	1971	61	1917	65	1963	1	B6	0.0	Z9B	.06	.00	4	0
09-007	F	1901	1965	01	1917	104	1960	33	C2	0.0	Z9C	1.83	.00	121	0
09-008	F	1900		01	1917	8	1960	20	C6	0.0	Z9C	1.12	.00	85	0
09-009	F	1893	1969	01	1915	78	1960	2	B6	0.0	Z9B	.11	.00	8	0
09-010	F	1897	1964	01	1914	40	1960	10	C6	0.0	Z9C	.58	.00	40	0
09-013	F	1900		01	1917	13	1971	4	B3	0.0	Z9B	.25	.00	19	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
09-015	M	1890	1972	04	1914	52	1960	0	G6	0.0	Z9	.00	.00	0	0
09-019	F	1903		01	1917	18	1975	0	B6	0.0	Z9B	.00	.00	0	0
09-020	F	1897	1968	01	1917	156	1963	1	B6	0.0	Z9B	.06	.00	4	0
09-024	M	1873	1960	06	1915	+0	1960	0	F6	0.0	Z9	.00	.00	0	0
09-026	F	1902		01	1917	48	1975	19	B2	0.0	Z9B	1.24	.00	94	0
09-028	F	1897		01	1916	78	1972	72	B1	0.0	Z9B	4.62	.00	352	0
09-029	F	1901	1962	01	1917	13	1960	16	C2	0.0	Z9C	.90	.00	58	0
09-031	F	1897		07	1913	364	1960	286	C2	0.0	Z9	16.18	.00	1236	0
09-032	F	1902	1969	01	1917	52	1969	97	B1	0.0	Z9B	6.00	.00	421	0
09-038	F	1903		01	1919	1	1960	0	B6	0.0	Z9B	.00	.00	0	0
09-041	M	1889	1952	06	1914	260	1965	114	A1	0.0	Z9A	4.15	.00	229	0
09-043	F	1898		01	1917	26	1971	11	B6	0.0	Z9B	.70	.00	53	0
09-044	F	1906	1955	01	1917	13	1975*	17	A2	0.0	Z9	.90	.00	52	0
09-046	F	1902	1967	01	1917	104	1960	10	C3	0.0	Z9C	.56	.00	38	0
09-049	F	1902		01	1915	+0	1969	14	G6	0.0	Z9	.89	.00	69	0
09-051	F	1900		01	1917	104	1960	50	C6	0.0	Z9C	2.78	.00	209	0
09-052	F	1900	1971	01	1916	52	1960	20	C6	0.0	Z9C	1.13	.00	83	0
09-053	M	1874	1966	04	1919	+0	1960	81	B1	0.0	Z9B	3.18	.00	210	0
09-057	F	1890	1973	01	1917	52	1960	0	B6	0.0	Z9B	.00	.00	0	0
09-058	F	1899		01	1917	39	1960	4	B6	0.0	Z9B	.22	.00	17	0
09-059	F	1903	1972	01	1917	1	1971	2	B6	0.0	Z9B	.13	.00	9	0
09-060	F	1899	1975	01	1917	65	1969	43	B2	0.0	Z9B	2.66	.00	200	0
09-061	F	1892		01	1914	208	1970	0	G6	0.0	Z9	.00	.00	0	0
09-062	F	1901		01	1918	52	1972	4	B3	0.0	Z9B	.25	.00	19	0
09-064	F	1891		01	1916	9	1960	0	B6	0.0	Z9B	.00	.00	0	0
09-065	F	1887		06	1914	78	1960	1	B6	0.0	Z9B	.06	.00	5	0
09-066	F	1899		01	1917	8	1972	2	B6	0.0	Z9B	.13	.00	10	0
09-070	M	1875	1967	06	1913	208	1960	3	B6	0.0	Z9B	.12	.00	9	0
09-071	F	1897		01	1917	104	1975	2	B6	0.0	Z9B	.13	.00	10	0
09-072	F	1893	1974	01	1917	39	1972	2	B6	0.0	Z9C	.14	.00	10	0
09-073	M	1886	1963	06	1916	468	1962	0	B6	0.0	Z9B	.00	.00	0	0
09-074	F	1892		01	1920	104	1962	13	G6	0.0	Z9	.71	.00	52	0
09-075	M	1893	1967	06	1913	884	1963	1	B6	0.0	Z9B	.04	.00	3	0
09-076	M	1882	1966	06	1913	1872	1964	14	D3	0.0	Z9D	.47	.00	25	0
09-077	M	1894		06	1914	520	1972	2	B6	0.0	Z9B	.09	.00	7	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
09-078	M	1883	1966	06	1911	832	1963	3	B6	0.0	Z9B	.12	.00	8	0
09-079	M	1891		06	1916	570	1962	0	G6	0.0	Z9	.00	.00	0	0
09-080	M	1886		06	1919	312	1962	5	G6	0.0	Z9	.19	.00	14	0
09-082	M	1892		06	1916	312	1974	4	B3	0.0	Z9B	.18	.00	14	0
09-083	M	1889	1964	06	1915	17	1962	5	G6	0.0	Z9	.21	.00	14	0
09-084	M	1888	1927	06	1912	576	1965	382	A1	0.0	Z9A	5.96	.00	131	0
09-086	M	1895		06	1921	78	1974	1	B6	0.0	Z9B	.04	.00	3	0
09-088	M	1900		06	1922	338	1971	18	B2	0.0	Z9B	.75	.00	51	0
09-089	M	1890	1973	06	1915	78	1959	64	C2	0.0	Z9C	2.58	.00	194	0
09-090	M	1888	1971	06	1913	78	1963	0	G6	0.0	Z9	.00	.00	0	0
09-095	M	1894	1975	06	1918	416	1975	0	B6	0.0	Z9B	.00	.00	0	0
09-096	M	1892		06	1919	17	1963	9	G6	0.0	Z9	.37	.00	27	0
09-097	M	1896		07	1916	988	1974	1	B6	0.0	Z9B	.04	.00	3	0
09-098	M	1902	1971	06	1921	104	1963	14	G6	0.0	Z9	.55	.00	37	0
09-099	M	1898	1971	06	1913	208	1963	1	G6	0.0	Z9	.04	.00	3	0
09-100	M	1888		06	1918	364	1963	9	G6	0.0	Z9	.35	.00	26	0
09-101	M	1884	1964	06	1920	39	1963	6	G6	0.0	Z9	.24	.00	15	0
09-102	M	1882	1951	04	1915	1	1964	150	A1	0.0	Z9A	5.50	.00	306	0
09-103	M	1895	1971	06	1918	416	1965	1	G6	0.0	Z9	.04	.00	3	0
09-104	M	1880	1967	06	1906	364	1965	42	B2	0.0	Z9B	1.93	.00	146	0
09-105	M	1886	1928	06	1912	728	1966	1390	A1	0.00093	A6	22.23	4.87	507	252
09-106	M	1901		06	1919	156	1974	0	B6	0.0	Z9B	.00	.00	0	0
09-107	M	1897	1974	06	1913	104	1965	1	G6	0.0	Z9	.04	.00	3	0
09-108	M	1891		06	1915	104	1965	4	G6	0.0	Z9	.17	.00	13	0
09-109	M	1895		06	1914	104	1965	4	G6	0.0	Z9	.17	.00	14	0
09-110	M	1900		06	1914	52	1965	7	G6	0.0	Z9	.31	.00	24	0
09-111	M	1874	1944	06	1913	520	1967	0	A6	0.0	Z9A	.00	.00	0	0
09-112	M	1898		06	1940	415	1966	64	G4	0.0	Z9	2.37	.00	120	0
09-115	M	1893		06	1920	52	1969	3	G6	0.0	Z9	.13	.00	9	0
09-117	F	1899		01	1917	24	1971	4	B3	0.0	Z9B	.25	.00	19	0
09-118	F	1901		07	1921	+0	1970	50	G4	0.0	Z9	3.01	.00	218	0
09-120	M	1889	1945	06	1918	104	1974	1	A6	0.0	Z9	.04	.00	2	0
09-123	M	1890		06	1917	156	1974	0	B6	0.0	Z9B	.00	.00	0	0
10-007	F	1916		01	1934	1144	1971	0	B6	0.0	Z9B	.00	.00	0	0
10-008	F	1904		01	1918	13	1972	2	B6	0.0	Z9B	.13	.00	9	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
10-010	F	1895	1975	05	1930	+0	1971	8600	B1	0.0	Z9C	472.25	.00	30382	0
10-012	M	1886	1941	05	1925	+0	1972	0	A6	0.0	Z9	.00	.00	0	0
10-018	F	1920		01	1952	416	1975	1	B6	0.0	Z9B	.04	.00	1	0
10-024	M	1914		06	1936	1612	1971	50	G4	0.0	Z9	1.19	.00	49	0
10-025	M	1937		07	1963	416	1971	7	B3	0.0	Z9C	.06	.00	1	0
10-026	M	1948		07	1968	200	1971	2	B6	0.0	Z9C	.01	.00	0	0
10-027	F	1928		01	1946	156	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-028	M	1886		06	1918	156	1971	0	B6	0.0	Z9B	.00	.00	0	0
10-031	F	1928		01	1946	52	1972	8	B2	0.0	Z9C	.36	.00	17	0
10-032	M	1937		07	1961	156	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-033	F	1927		01	1946	264	1974	3	B3	0.0	Z9C	.15	.00	7	0
10-034	F	1919		01	1943	202	1973	9	B2	0.0	Z9C	.40	.00	20	0
10-035	F	1922		01	1942	639	1974	10	B2	0.0	Z9C	.44	.00	20	0
10-036	F	1920		76	1945	208	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-037	F	1927		01	1951	52	1972	12	B2	0.0	Z9C	.45	.00	19	0
10-038	F	1929		01	1947	78	1974	1	B6	0.0	Z9C	.02	.00	1	0
10-039	F	1922		07	1942	260	1972	4	B3	0.0	Z9C	.17	.00	9	0
10-040	F	1917		01	1946	+0	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-041	F	1924		01	1943	13	1972	1	B6	0.0	Z9C	.04	.00	2	0
10-042	F	1927		01	1947	130	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-043	F	1919		05	1941	8	1975	0	B6	0.0	Z9B	.00	.00	0	0
10-044	F	1925		01	1948	13	1972	19	B2	0.0	Z9C	.80	.00	37	0
10-045	F	1923		01	1946	13	1972	1	B6	0.0	Z9C	.04	.00	2	0
10-046	F	1927		17	1947	208	1975	0	B6	0.0	Z9C	.00	.00	0	0
10-047	F	1924		01	1942	52	1974	10	B2	0.0	Z9C	.46	.00	24	0
10-048	F	1894		06	1917	156	1972	3	B6	0.0	Z9C	.19	.00	14	0
10-049	F	1926		01	1946	104	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-050	F	1920		01	1943	104	1974	11	B2	0.0	Z9C	.49	.00	25	0
10-051	M	1914		06	1931	468	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-053	F	1926		17	1946	260	1972	2	B6	0.0	Z9C	.07	.00	3	0
10-054	F	1926		71	1943	364	1972	1	B6	0.0	Z9C	.06	.00	3	0
10-055	M	1922		08	1922	39	1972	0	B6	0.00040	Z7B	.00	.00	0	0
10-056	M	1924		08	1924	39	1972	2	B6	0.00040	Z7B	.08	.01	6	1
10-057	F	1929		01	1946	52	1972	1	B6	0.0	Z9C	.06	.00	3	0
10-058	F	1923		01	1941	208	1972	6	B3	0.0	Z9C	.28	.00	15	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
10-059	F	1915		01	1944	104	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-060	F	1919		01	1943	104	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-061	F	1923		07	1939	260	1972	6	B3	0.0	Z9C	.28	.00	15	0
10-062	F	1920		01	1939	182	1972	1	B6	0.0	Z9C	.06	.00	3	0
10-063	F	1911		01	1928	624	1972	2	B6	0.0	Z9C	.11	.00	7	0
10-064	F	1921		07	1943	156	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-065	F	1920		01	1941	260	1972	0	B6	0.0	Z9C	.01	.00	1	0
10-066	F	1924		01	1942	104	1972	12	B2	0.0	Z9C	.54	.00	28	0
10-067	F	1923		01	1942	468	1972	8	B2	0.0	Z9C	.35	.00	17	0
10-068	F	1918		71	1942	78	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-069	F	1923		01	1947	1300	1972	3	B3	0.0	Z9C	.15	.00	5	0
10-070	F	1921		01	1945	1352	1974	14	B2	0.0	Z9C	.40	.00	14	0
10-071	F	1924		01	1943	1508	1972	13	B2	0.0	Z9C	.28	.00	10	0
10-072	F	1924		01	1947	1300	1972	12	B2	0.0	Z9C	.24	.00	8	0
10-073	M	1919		07	1953	208	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-074	M	1921		06	1950	1248	1974	48	B2	0.0	Z9C	.69	.00	19	0
10-075	F	1929		01	1949	260	1972	5	B3	0.0	Z9C	.20	.00	9	0
10-076	F	1923		01	1951	52	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-077	F	1920		01	1951	17	1972	1	B6	0.0	Z9C	.02	.00	1	0
10-078	F	1923		01	1941	676	1974	13	B1	0.0	Z9C	.58	.00	27	0
10-079	F	1920		01	1940	624	1974	13	B3	0.0	Z9C	.58	.00	28	0
10-080	F	1913		76	1943	1508	1972	5	B3	0.0	Z9C	.11	.00	4	0
10-081	F	1916		01	1946	104	1972	5	B3	0.0	Z9C	.22	.00	10	0
10-082	F	1915		01	1951	758	1972	5	B3	0.0	Z9C	.15	.00	5	0
10-083	F	1924		01	1943	104	1972	5	B3	0.0	Z9C	.23	.00	12	0
10-084	F	1928		71	1946	82	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-085	M	1946		71	1964	17	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-086	F	1915		01	1943	156	1972	3	B6	0.0	Z9C	.11	.00	6	0
10-087	F	1920		01	1942	1560	1972	19	B2	0.0	Z9C	.43	.00	15	0
10-088	F	1923		17	1946	260	1972	3	B6	0.0	Z9C	.11	.00	5	0
10-089	F	1921		01	1942	13	1972	0	B6	0.0	Z9C	.02	.00	1	0
10-090	F	1922		01	1941	78	1972	1	B6	0.0	Z9C	.06	.00	3	0
10-091	M	1883	1952	05	1930	+0	1974	423	A1	0.0	Z9A	12.00	.00	487	0
10-094	M	1905	1974	07	1919	104	1972	0	B6	0.00240	Z7C	.00	.00	0	0
10-095	F	1927		01	1946	260	1972	5	B3	0.0	Z9C	.21	.00	10	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
10-096	F	1930		01	1951	832	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-097	F	1919		01	1943	364	1972	4	B3	0.0	Z9C	.15	.00	7	0
10-098	F	1917		01	1935	208	1972	4	B3	0.0	Z9C	.20	.00	11	0
10-099	F	1924		01	1942	104	1974	19	B2	0.0	Z9C	.89	.00	46	0
10-100	F	1924		76	1942	78	1972	7	B3	0.0	Z9C	.34	.00	17	0
10-101	F	1925		01	1943	208	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-102	F	1926		01	1944	60	1972	1	B6	0.0	Z9C	.03	.00	2	0
10-103	F	1912		01	1946	104	1972	2	B6	0.0	Z9C	.08	.00	4	0
10-104	F	1929		01	1948	208	1972	2	B6	0.0	Z9C	.10	.00	4	0
10-105	F	1927		01	1946	260	1972	0	C6	0.0	Z9C	.00	.00	0	0
10-106	F	1925		01	1946	104	1972	1	B6	0.0	Z9C	.04	.00	2	0
10-107	F	1909		01	1926	9	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-108	F	1916		04	1950	+0	1972	3	B6	0.0	Z9C	.12	.00	5	0
10-109	F	1951		07	1969	78	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-110	F	1917		01	1946	520	1972	0	B6	0.0	Z9C	.01	.00	0	0
10-111	F	1906		01	1923	2	1972	4	B3	0.0	Z9C	.27	.00	19	0
10-112	M	1902		01	1923	+0	1972	1	B6	0.0	Z9C	.04	.00	3	0
10-113	F	1924		01	1942	52	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-114	F	1937		01	1970	104	1972	1	B6	0.0	Z9C	.01	.00	0	0
10-115	F	1921		07	1970	130	1972	1	B6	0.0	Z9C	.00	.00	0	0
10-116	F	1924		01	1969	169	1972	15	B6	0.0	Z9C	.11	.00	2	0
10-117	F	1924		01	1967	208	1972	2	B6	0.0	Z9C	.03	.00	1	0
10-118	F	1924		01	1945	1352	1972	23	B2	0.0	Z9C	.59	.00	20	0
10-119	F	1952		71	1971	82	1972	2	B6	0.0	Z9C	.01	.00	0	0
10-120	F	1950		01	1971	98	1974	4	C3	0.0	Z9C	.04	.00	1	0
10-121	F	1926		01	1945	17	1972	1	B6	0.0	Z9C	.02	.00	1	0
10-122	F	1921		07	1921	+0	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-125	F	1903		01	1917	8	1975	1	B6	0.0	Z9B	.07	.00	5	0
10-126	F	1927		01	1946	13	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-128	F	1923		01	1942	364	1972	6	B3	0.0	Z9C	.28	.00	14	0
10-129	F	1923		01	1942	269	1975	9	B2	0.0	Z9C	.42	.00	21	0
10-130	F	1922		01	1942	147	1975	14	B2	0.0	Z9C	.66	.00	34	0
10-131	F	1917		07	1941	260	1972	1	B6	0.0	Z9C	.05	.00	2	0
10-132	F	1929		07	1970	130	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-133	F	1910		01	1941	1248	1972	1	B6	0.0	Z9C	.05	.00	2	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
10-134	F	1913		01	1932	1872	1972	1	B6	0.0	Z9C	.03	.00	1	0
10-135	F	1922		01	1939	130	1972	6	B3	0.0	Z9C	.29	.00	16	0
10-136	F	1920		01	1941	26	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-137	F	1918		01	1935	117	1972	1	B6	0.0	Z9C	.03	.00	1	0
10-139	F	1922		01	1942	130	1972	3	B6	0.0	Z9C	.13	.00	7	0
10-140	F	1935		07	1956	17	1972	2	B6	0.0	Z9C	.06	.00	2	0
10-141	F	1918		01	1965	104	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-142	F	1922		01	1942	156	1972	2	B6	0.0	Z9C	.10	.00	5	0
10-144	F	1926		01	1945	156	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-145	F	1928		07	1946	130	1972	15	B2	0.0	Z9C	.63	.00	30	0
10-146	F	1921		01	1940	364	1972	4	B3	0.0	Z9C	.16	.00	8	0
10-147	F	1927		01	1946	156	1972	2	B6	0.0	Z9C	.09	.00	4	0
10-148	F	1913		01	1935	13	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-149	F	1924		01	1945	104	1972	4	B3	0.0	Z9C	.19	.00	9	0
10-150	F	1889		01	1919	13	1972	0	G6	0.0	Z9	.00	.00	0	0
10-151	M	1887		06	1915	520	1974	0	G8	0.0	Z9	.00	.00	0	0
10-152	F	1923		01	1941	52	1972	2	B6	0.0	Z9B	.09	.00	5	0
10-153	F	1921		01	1941	234	1972	1	B6	0.0	Z9B	.05	.00	2	0
10-162	F	1931		01	1951	13	1974	3	B2	0.0	Z9C	.12	.00	5	0
10-164	F	1915		01	1937	156	1974	0	B6	0.0	Z9C	.01	.00	0	0
10-165	F	1919		01	1942	416	1972	2	B6	0.0	Z9C	.09	.00	4	0
10-171	F	1924		01	1942	156	1974	3	B3	0.0	Z9C	.13	.00	7	0
10-172	F	1930		07	1948	60	1974	3	B3	0.0	Z9C	.15	.00	7	0
10-173	F	1915		01	1948	123	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-180	F	1919		01	1941	728	1974	9	B2	0.0	Z9C	.37	.00	17	0
10-181	F	1912		01	1931	287	1973	5	B3	0.0	Z9C	.24	.00	15	0
10-190	F	1921		01	1946	156	1972	3	B6	0.0	Z9C	.12	.00	5	0
10-191	F	1940		71	1971	17	1972	2	B6	0.0	Z9C	.02	.00	0	0
10-192	F	1924		01	1942	78	1974	3	B3	0.0	Z9C	.13	.00	7	0
10-193	F	1921		01	1941	104	1972	3	B6	0.0	Z9C	.13	.00	7	0
10-195	F	1920		01	1937	1560	1973	11	C3	0.0	Z9C	.40	.00	17	0
10-198	F	1920		01	1946	378	1973	15	B2	0.0	Z9C	.62	.00	28	0
10-201	F	1918		71	1946	1352	1972	9	B2	0.0	Z9C	.18	.00	6	0
10-202	F	1925		01	1947	49	1974	2	B6	0.0	Z9C	.07	.00	3	0
10-203	F	1926		01	1946	0	1974	2	B6	0.0	Z9C	.07	.00	3	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
10-204	F	1950		07	1971	43	1972	6	B3	0.0	Z9C	.03	.00	0	0
10-205	F	1923		01	1942	39	1972	1	B6	0.0	Z9C	.06	.00	3	0
10-206	F	1924		01	1943	230	1972	6	B3	0.0	Z9C	.27	.00	13	0
10-207	F	1923		61	1942	208	1972	12	B2	0.0	Z9C	.53	.00	27	0
10-208	F	1922		01	1941	2	1972	1	B6	0.0	Z9C	.03	.00	2	0
10-209	F	1920		01	1942	69	1972	6	B3	0.0	Z9C	.27	.00	14	0
10-210	F	1909		01	1926	1040	1972	17	B2	0.0	Z9C	.85	.00	50	0
10-212	M	1950		07	1971	55	1973	1	B6	0.0	Z9C	.01	.00	0	0
10-213	M	1951		07	1971	45	1973	1	B6	0.0	Z9C	.00	.00	0	0
10-214	F	1942		07	1972	30	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-215	F	1921		01	1943	208	1972	1	B6	0.0	Z9C	.04	.00	2	0
10-216	F	1916		01	1946	1456	1973	2	B6	0.0	Z9C	.04	.00	1	0
10-218	F	1915		01	1934	492	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-219	F	1916		01	1942	364	1973	24	B2	0.0	Z9B	1.07	.00	52	0
10-221	F	1917		01	1941	676	1973	1	B6	0.0	Z9B	.04	.00	2	0
10-222	F	1919		01	1941	234	1972	0	G6	0.0	Z9	.00	.00	0	0
10-225	F	1911		01	1933	1872	1972	4	B3	0.0	Z9C	.15	.00	6	0
10-226	F	1923		01	1941	1612	1972	3	B6	0.0	Z9C	.06	.00	2	0
10-227	M	1912		71	1928	2288	1972	6	B3	0.0	Z9C	.12	.00	5	0
10-228	F	1912		01	1940	1508	1975*	0	B6	0.0	Z9C	.00	.00	0	0
10-229	F	1920		01	1942	260	1972	1	B6	0.0	Z9C	.05	.00	2	0
10-230	F	1929		01	1948	13	1973	0	C6	0.0	Z9C	.00	.00	0	0
10-234	F	1928	1972	07	1959	884	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-236	F	1919		01	1949	156	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-237	F	1910		01	1940	156	1972	4	B3	0.0	Z9C	.20	.00	10	0
10-239	M	1908		06	1934	1300	1973	2	B6	0.0	Z9B	.06	.00	3	0
10-241	F	1904		01	1922	17	1972	0	C6	0.0	Z9C	.00	.00	0	0
10-242	F	1947		07	1966	156	1974	1	B6	0.0	Z9C	.01	.00	0	0
10-244	F	1916		01	1942	1	1972	0	B6	0.0	Z9C	.02	.00	1	0
10-245	M	1914		67	1941	104	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-247	M	1915		07	1948	364	1972	1	B6	0.0	Z9C	.02	.00	1	0
10-249	M	1943		07	1963	130	1973	1	B6	0.0	Z9C	.01	.00	0	0
10-250	F	1938		07	1956	30	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-251	F	1923		01	1941	65	1974	2	B3	0.0	Z9C	.09	.00	5	0
10-252	F	1919		01	1935	416	1972	4	B3	0.0	Z9C	.19	.00	11	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
10-254	F	1905		07	1953	832	1972	0	B6	0.0	Z9C	.01	.00	0	0
10-256	F	1917		01	1940	78	1972	1	B6	0.0	Z9B	.05	.00	3	0
10-257	F	1932		07	1951	104	1972	0	B6	0.0	Z9C	.01	.00	0	0
10-258	F	1923		01	1943	26	1972	3	B6	0.0	Z9C	.13	.00	7	0
10-261	F	1922		01	1940	104	1972	3	B6	0.0	Z9C	.13	.00	7	0
10-262	F	1919		01	1941	104	1973	2	B6	0.0	Z9C	.08	.00	4	0
10-263	F	1921		01	1941	130	1972	2	B6	0.0	Z9B	.09	.00	5	0
10-266	F	1905		01	1926	2236	1973	2	B6	0.0	Z9C	.07	.00	3	0
10-269	F	1925		01	1945	17	1972	0	B6	0.0	Z9C	.00	.00	0	0
10-270	F	1926		71	1946	104	1972	1	B6	0.0	Z9C	.02	.00	1	0
10-272	F	1915		01	1935	52	1972	2	B6	0.0	Z9C	.09	.00	5	0
10-273	F	1929		01	1948	22	1973	2	B6	0.0	Z9C	.08	.00	4	0
10-274	F	1924		01	1946	62	1973	3	B3	0.0	Z9C	.15	.00	7	0
10-276	F	1932		01	1951	6	1973	1	B6	0.0	Z9C	.02	.00	1	0
10-277	F	1915		71	1946	154	1973	1	B6	0.0	Z9C	.02	.00	1	0
10-278	F	1908		71	1929	1872	1973	3	B3	0.0	Z9C	.12	.00	5	0
10-279	F	1937		01	1955	728	1973	2	B6	0.0	Z9C	.04	.00	1	0
10-280	F	1904		07	1921	2132	1973	2	B6	0.0	Z9C	.09	.00	5	0
10-281	F	1931		01	1950	416	1973	1	B6	0.0	Z9C	.02	.00	1	0
10-282	F	1921	1974	01	1941	22	1974	2	C6	0.0	Z9C	.09	.00	5	0
10-283	F	1918		01	1937	208	1974	0	B6	0.0	Z9C	.01	.00	1	0
10-284	F	1918		71	1936	1456	1974	3	B3	0.0	Z9C	.12	.00	5	0
10-285	M	1917		07	1935	81	1973	0	G6	0.0	Z9	.00	.00	0	0
10-286	F	1937		07	1968	104	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-287	F	1923		01	1944	2	1973	1	B6	0.0	Z9C	.06	.00	3	0
10-291	F	1916		01	1934	156	1973	4	B3	0.0	Z9C	.23	.00	13	0
10-292	F	1913	1975	01	1934	102	1973	6	B3	0.0	Z9C	.33	.00	20	0
10-293	F	1938		07	1970	24	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-294	F	1916		01	1934	416	1974	2	B6	0.0	Z9C	.08	.00	4	0
10-295	M	1923		07	1946	282	1973	2	B6	0.0	Z9C	.04	.00	2	0
10-296	F	1930		01	1948	50	1973	0	B6	0.0	Z9C	.01	.00	0	0
10-297	F	1929	1973	07	1969	66	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-299	F	1923		01	1942	43	1973	6	B3	0.0	Z9C	.30	.00	16	0
10-300	F	1911		01	1940	1612	1973	1	B6	0.0	Z9C	.04	.00	1	0
10-301	M	1930		07	1949	69	1973	0	B6	0.0	Z9C	.01	.00	0	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
10-302	F	1917		07	1933	312	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-304	F	1926		01	1950	364	1973	2	B6	0.0	Z9C	.09	.00	4	0
10-306	F	1907		01	1923	4	1973	4	B3	0.0	Z9C	.24	.00	17	0
10-307	F	1893	1948	05	1930	+0	1974	85	A2	0.0	Z9A	3.04	.00	109	0
10-309	F	1925		01	1943	28	1973	2	B6	0.0	Z9C	.08	.00	4	0
10-310	F	1916		01	1936	53	1973	2	B6	0.0	Z9C	.09	.00	5	0
10-311	F	1919		01	1943	16	1973	0	B6	0.0	Z9C	.01	.00	0	0
10-312	F	1923		01	1943	16	1973	2	B6	0.0	Z9C	.07	.00	4	0
10-313	F	1924		01	1942	110	1973	9	B3	0.0	Z9C	.42	.00	22	0
10-314	F	1918		01	1943	119	1973	4	B3	0.0	Z9C	.18	.00	9	0
10-316	M	1946		07	1965	167	1973	2	B6	0.0	Z9C	.04	.00	1	0
10-319	F	1912		07	1934	832	1973	6	B3	0.0	Z9C	.27	.00	14	0
10-320	M	1918		07	1939	1352	1973	1	B6	0.0	Z9C	.03	.00	1	0
10-321	F	1910		01	1942	1456	1973	2	B6	0.0	Z9C	.06	.00	2	0
10-322	F	1904		07	1936	1092	1973	3	B3	0.0	Z9C	.14	.00	7	0
10-324	F	1912		01	1926	13	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-325	M	1952		07	1970	22	1974	1	B6	0.0	Z9	.02	.00	0	0
10-326	F	1954		07	1973	39	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-329	F	1914		07	1938	884	1973	1	B6	0.0	Z9C	.03	.00	1	0
10-330	F	1921		07	1945	520	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-331	F	1911		07	1934	162	1973	2	B6	0.0	Z9B	.10	.00	6	0
10-333	F	1915		01	1941	208	1973	1	B6	0.0	Z9B	.05	.00	2	0
10-334	F	1921		01	1943	26	1973	0	B6	0.0	Z9B	.00	.00	0	0
10-335	F	1939		07	1969	24	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-336	F	1923		07	1943	1092	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-337	M	1892	1971	06	1913	260	1974	1	A6	0.0	Z9A	.03	.00	2	0
10-340	F	1920		67	1942	104	1974	6	B3	0.0	Z9B	.28	.00	15	0
10-341	F	1919		01	1939	312	1973	1	B6	0.0	Z9B	.05	.00	2	0
10-347	M	1947		08	1947	39	1973	1	B6	0.0	Z9B	.03	.00	1	0
10-348	F	1921		01	1941	104	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-350	F	1924		01	1941	27	1973	1	B6	0.0	Z9C	.04	.00	2	0
10-351	M	1931		07	1964	14	1973	1	B6	0.0	Z9C	.02	.00	1	0
10-352	F	1926		07	1947	104	1974	1	B6	0.0	Z9C	.04	.00	2	0
10-353	F	1922		01	1942	21	1973	1	B6	0.0	Z9C	.02	.00	1	0
10-356	F	1915		07	1947	46	1973	1	B6	0.0	Z9C	.03	.00	2	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
10-357	F	1923		01	1942	68	1973	3	B3	0.0	Z9C	.15	.00	8	0
10-358	F	1920		01	1946	16	1973	3	B3	0.0	Z9C	.12	.00	6	0
10-359	M	1950		07	1971	32	1973	3	B3	0.0	Z9C	.02	.00	0	0
10-360	F	1919		01	1941	46	1975*	0	B6	0.0	Z9B	.00	.00	0	0
10-362	F	1922		01	1941	364	1973	4	B3	0.0	Z9C	.19	.00	9	0
10-365	F	1920		01	1939	260	1973	0	B6	0.0	Z9C	.01	.00	1	0
10-367	F	1919		01	1940	260	1973	1	B6	0.0	Z9C	.03	.00	2	0
10-375	F	1924		01	1943	20	1973	1	B6	0.0	Z9C	.06	.00	3	0
10-377	F	1898		07	1923	1976	1973	1	B6	0.0	Z9C	.05	.00	3	0
10-378	F	1906		07	1946	520	1973	5	B3	0.0	Z9C	.19	.00	8	0
10-379	F	1917		01	1941	89	1973	25	B1	0.0	Z9C	1.21	.00	64	0
10-381	F	1927		01	1946	27	1973	6	B3	0.0	Z9C	.25	.00	12	0
10-382	F	1923		01	1942	119	1973	5	B3	0.0	Z9C	.25	.00	13	0
10-384	F	1919		71	1943	884	1973	1	B6	0.0	Z9C	.05	.00	2	0
10-385	F	1921		07	1964	16	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-386	F	1933		01	1953	52	1973	1	B6	0.0	Z9C	.05	.00	2	0
10-387	F	1928		01	1947	15	1973	0	B6	0.0	Z9C	.01	.00	0	0
10-389	F	1919		01	1943	24	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-390	F	1923		01	1942	38	1973	3	B3	0.0	Z9C	.15	.00	8	0
10-392	F	1903		71	1932	520	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-393	F	1907		01	1925	208	1973	2	B6	0.0	Z9C	.11	.00	7	0
10-394	F	1907		01	1923	728	1974	1	B6	0.0	Z9C	.03	.00	2	0
10-395	F	1908		01	1925	262	1973	3	B3	0.0	Z9C	.20	.00	13	0
10-397	F	1927		01	1946	16	1973	1	B6	0.0	Z9C	.03	.00	1	0
10-398	F	1918		71	1951	624	1973	1	B6	0.0	Z9C	.03	.00	1	0
10-409	F	1921		01	1943	118	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-410	F	1926		01	1943	52	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-411	F	1920		01	1942	14	1973	3	B3	0.0	Z9C	.14	.00	7	0
10-412	F	1908		01	1925	13	1973	1	B6	0.0	Z9C	.03	.00	2	0
10-414	F	1926		01	1948	104	1973	1	B6	0.0	Z9C	.05	.00	2	0
10-415	F	1943		07	1973	8	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-419	M	1913		06	1936	1924	1973	6	B3	0.0	Z9C	.10	.00	4	0
10-432	F	1920		01	1940	104	1975*	0	B6	0.0	Z9C	.02	.00	1	0
10-439	F	1925		01	1943	20	1973	2	B6	0.0	Z9C	.09	.00	5	0
10-440	F	1920		01	1948	1	1973	0	B6	0.0	Z9C	.00	.00	0	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
10-442	F	1932		01	1951	8	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-444	F	1927		01	1949	4	1973	1	B6	0.0	Z9C	.02	.00	1	0
10-445	F	1924		01	1943	2	1973	2	B6	0.0	Z9C	.10	.00	5	0
10-446	F	1920		01	1939	3	1973	1	B6	0.0	Z9C	.04	.00	2	0
10-447	F	1929		01	1947	5	1973	6	B3	0.0	Z9C	.26	.00	12	0
10-451	F	1921		01	1945	3	1973	0	B6	0.0	Z9C	.01	.00	1	0
10-453	F	1927		01	1943	1	1973	0	B6	0.0	Z9C	.01	.00	1	0
10-454	F	1926		01	1942	5	1973	0	B6	0.0	Z9C	.02	.00	1	0
10-455	F	1909		01	1928	104	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-457	F	1921		01	1941	65	1973	1	B6	0.0	Z9C	.06	.00	3	0
10-458	M	1927		01	1954	1040	1973	24	B2	0.0	Z9C	.31	.00	8	0
10-459	F	1923		01	1956	832	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-460	F	1936		01	1959	676	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-461	M	1925		06	1948	1300	1973	10	B2	0.0	Z9C	.14	.00	4	0
10-462	M	1927		06	1951	1144	1973	8	B3	0.0	Z9C	.11	.00	3	0
10-464	M	1940		07	1961	12	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-465	F	1924		01	1942	8	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-470	F	1924		01	1943	176	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-471	F	1924		01	1943	34	1973	3	B3	0.0	Z9C	.13	.00	7	0
10-472	F	1928		01	1947	12	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-473	F	1926		01	1945	18	1973	0	B6	0.0	Z9C	.02	.00	1	0
10-474	F	1921		01	1946	77	1974	2	B6	0.0	Z9C	.09	.00	4	0
10-475	F	1927		07	1946	90	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-476	F	1928		01	1945	11	1973	1	B6	0.0	Z9C	.02	.00	1	0
10-477	F	1924		01	1944	42	1975*	2	B3	0.0	Z9C	.11	.00	6	0
10-478	F	1922		01	1940	10	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-479	F	1926		01	1946	11	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-480	F	1924		01	1943	4	1973	0	B6	0.0	Z9C	.02	.00	1	0
10-481	F	1925		01	1940	5	1973	1	B6	0.0	Z9C	.06	.00	3	0
10-482	F	1925		01	1943	28	1973	4	B3	0.0	Z9C	.20	.00	10	0
10-483	M	1934		07	1950	5	1973	2	B6	0.0	Z9C	.05	.00	2	0
10-485	F	1918		01	1948	4	1973	0	B6	0.0	Z9C	.01	.00	1	0
10-486	F	1919		01	1942	32	1973	0	B6	0.0	Z9C	.01	.00	0	0
10-487	F	1924		01	1943	220	1973	0	B6	0.0	Z9C	.01	.00	0	0
10-488	F	1921		01	1942	20	1973	0	B6	0.0	Z9C	.00	.00	0	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
10-490	F	1922		01	1943	20	1974	8	B2	0.0	Z9C	.36	.00	19	0
10-492	F	1925		01	1945	326	1973	2	B6	0.0	Z9C	.07	.00	3	0
10-494	F	1913		01	1939	312	1973	1	B6	0.0	Z9C	.03	.00	1	0
10-495	F	1924		01	1942	312	1973	0	B6	0.0	Z9B	.00	.00	0	0
10-496	F	1922		01	1940	108	1975*	0	B6	0.0	Z9C	.00	.00	0	0
10-501	F	1928		01	1946	15	1973	2	B6	0.0	Z9C	.08	.00	4	0
10-502	F	1928		01	1946	13	1973	2	B6	0.0	Z9C	.08	.00	4	0
10-505	F	1933		01	1951	3	1973	2	B6	0.0	Z9C	.08	.00	4	0
10-506	F	1920		07	1946	4	1973	0	B6	0.0	Z9C	.02	.00	1	0
10-510	F	1924		07	1942	26	1973	1	B6	0.0	Z9C	.06	.00	3	0
10-511	F	1923		01	1943	12	1973	5	B3	0.0	Z9C	.23	.00	12	0
10-512	F	1936		01	1965	1	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-518	F	1905		06	1928	1196	1973	2	B6	0.0	Z9B	.07	.00	4	0
10-520	F	1924		01	1942	5	1973	1	B6	0.0	Z9C	.05	.00	2	0
10-521	F	1923		01	1955	416	1973	1	B6	0.0	Z9C	.04	.00	1	0
10-523	F	1922		01	1942	17	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-525	F	1928		01	1947	1	1973	1	B6	0.0	Z9C	.04	.00	2	0
10-530	F	1952		07	1971	52	1973	3	B6	0.0	Z9C	.02	.00	0	0
10-531	F	1924		01	1946	1	1973	2	B6	0.0	Z9C	.08	.00	4	0
10-532	F	1916		01	1942	2	1973	1	B6	0.0	Z9C	.06	.00	3	0
10-533	F	1925		01	1943	5	1973	2	B6	0.0	Z9C	.09	.00	5	0
10-534	F	1925		01	1946	54	1973	2	C6	0.0	Z9C	.09	.00	4	0
10-535	F	1927		01	1946	16	1973	1	C6	0.0	Z9C	.04	.00	2	0
10-536	F	1927		01	1942	1	1973	1	B6	0.0	Z9C	.05	.00	3	0
10-538	M	1896		07	1941	1664	1973	2	B6	0.0	Z9C	.03	.00	1	0
10-540	M	1917		07	1939	1768	1973	2	B6	0.0	Z9C	.04	.00	1	0
10-543	M	1891		06	1916	26	1973	3	B3	0.0	Z9B	.14	.00	11	0
10-546	F	1906		07	1929	208	1973	5	B3	0.0	Z9C	.26	.00	17	0
10-549	F	1919		01	1941	62	1973	4	B3	0.0	Z9C	.21	.00	11	0
10-550	F	1914		17	1965	230	1973	1	B6	0.0	Z9C	.02	.00	0	0
10-557	F	1921		01	1942	43	1974	4	B3	0.0	Z9C	.19	.00	10	0
10-558	M	1927		07	1951	+0	1973	5	B3	0.0	Z9C	.14	.00	6	0
10-559	F	1919		01	1941	69	1973	2	B6	0.0	Z9C	.08	.00	4	0
10-560	F	1923		01	1942	96	1973	4	B3	0.0	Z9C	.17	.00	9	0
10-561	M	1906		06	1927	52	1973	6	B6	0.0	Z9B	.25	.00	17	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
10-566	M	1914		02	1930	13	1973	3	B6	0.00480	Z5B	.12	.11	8	8
10-569	F	1925		01	1946	1	1975*	0	B6	0.0	Z9C	.00	.00	0	0
10-570	M	1907		06	1934	780	1973	0	B6	0.0	Z9C	.01	.00	1	0
10-573	F	1922		01	1944	14	1973	3	B3	0.0	Z9C	.12	.00	6	0
10-574	M	1908		71	1930	2236	1973	7	B2	0.0	Z9C	.14	.00	6	0
10-575	F	1930		01	1948	1040	1973	4	B3	0.0	Z9C	.12	.00	4	0
10-579	M	1926		07	1948	1248	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-580	F	1930		01	1948	52	1973	3	B3	0.0	Z9C	.11	.00	5	0
10-582	F	1938		01	1965	416	1973	1	B6	0.0	Z9C	.01	.00	0	0
10-583	M	1913		06	1939	1352	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-584	F	1925		01	1942	3	1973	1	B6	0.0	Z9C	.04	.00	2	0
10-585	M	1908		06	1930	52	1973	2	B6	0.0	Z9C	.08	.00	5	0
10-587	M	1946		07	1966	416	1973	1	B6	0.0	Z9C	.01	.00	0	0
10-588	F	1910		01	1927	2	1974	0	G6	0.00330	Z8	.00	.00	0	0
10-589	M	1938		07	1971	780	1973	2	B3	0.0	Z9C	.02	.00	0	0
10-590	M	1912		06	1948	728	1974	0	B6	0.0	Z9B	.00	.00	0	0
10-592	M	1899		06	1923	1300	1973	0	B6	0.0	Z9B	.00	.00	0	0
10-594	F	1917		01	1943	5	1973	5	B3	0.0	Z9C	.24	.00	12	0
10-596	F	1909		01	1927	6	1973	6	B3	0.0	Z9C	.32	.00	21	0
10-598	F	1914		01	1934	156	1973	1	B6	0.0	Z9C	.04	.00	2	0
10-601	M	1920		07	1951	0	1975*	0	B6	0.0	Z9B	.00	.00	0	0
10-606	F	1910		07	1928	468	1975*	0	B6	0.0	Z9B	.00	.00	0	0
10-608	F	1917		01	1936	4	1975*	1	B6	0.0	Z9C	.03	.00	2	0
10-609	F	1925		01	1943	42	1973	2	B6	0.0	Z9C	.07	.00	4	0
10-610	F	1920		01	1941	22	1975*	2	B3	0.0	Z9C	.08	.00	5	0
10-611	F	1924		01	1942	13	1973	2	B6	0.0	Z9C	.09	.00	5	0
10-613	F	1919		01	1945	12	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-614	F	1915		01	1942	30	1975*	1	B6	0.0	Z9C	.04	.00	2	0
10-616	F	1929		01	1948	15	1973	2	B6	0.0	Z9C	.07	.00	3	0
10-617	F	1922		01	1942	182	1974	10	B2	0.0	Z9C	.47	.00	24	0
10-618	F	1923		01	1942	130	1975*	0	B6	0.0	Z9C	.01	.00	1	0
10-621	M	1905		06	1925	1716	1973	1	B6	0.0	Z9B	.03	.00	1	0
10-623	M	1917		06	1938	1144	1973	1	B6	0.0	Z9B	.03	.00	1	0
10-627	M	1911		07	1928	208	1974	4	G6	0.00420	Z5	.16	.14	10	11
10-630	F	1915		01	1937	13	1973	0	B6	0.0	Z9C	.01	.00	1	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
10-631	F	1929		01	1946	26	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-635	F	1922		01	1943	156	1973	3	B6	0.0	Z9C	.11	.00	6	0
10-644	M	1870	1927	05	1927	0	1975*	5300	A1	0.0	Z9	4.14	.00	4	0
10-645	F	1930		76	1948	90	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-648	F	1923		01	1942	30	1974	2	B6	0.0	Z9C	.08	.00	4	0
10-649	F	1921		01	1942	15	1973	2	B6	0.0	Z9C	.08	.00	4	0
10-650	F	1926		01	1946	59	1973	8	B2	0.0	Z9C	.34	.00	16	0
10-651	F	1923		01	1942	260	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-653	F	1926		01	1946	16	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-656	F	1923		01	1942	20	1973	1	B6	0.0	Z9C	.03	.00	2	0
10-657	F	1922		01	1943	13	1973	1	B6	0.0	Z9C	.05	.00	3	0
10-658	F	1906		01	1927	208	1974	6	B2	0.0	Z9C	.34	.00	22	0
10-659	F	1904		01	1927	52	1974	0	B6	0.0	Z9C	.02	.00	2	0
10-660	F	1924		01	1942	172	1973	18	B2	0.0	Z9C	.84	.00	43	0
10-662	F	1909		01	1930	13	1973	1	B6	0.0	Z9C	.03	.00	2	0
10-664	F	1925		01	1940	1	1973	3	B3	0.0	Z9C	.15	.00	8	0
10-665	F	1927		01	1946	104	1973	1	B6	0.0	Z9C	.05	.00	2	0
10-666	F	1924		01	1943	13	1974	1	B6	0.0	Z9C	.03	.00	1	0
10-667	F	1908	1974	01	1925	52	1973	7	B2	0.0	Z9C	.39	.00	26	0
10-668	F	1925		01	1943	19	1973	1	B6	0.0	Z9C	.04	.00	2	0
10-670	M	1932		06	1955	780	1974	2	B3	0.0	Z9C	.03	.00	1	0
10-672	M	1916		06	1936	1040	1974	0	B6	0.0	Z9B	.00	.00	0	0
10-673	M	1911		06	1932	364	1973	0	B6	0.0	Z9B	.00	.00	0	0
10-683	F	1924		01	1942	14	1973	0	B6	0.0	Z9C	.00	.00	0	0
10-684	M	1927		07	1950	104	1974	1	B6	0.0	Z9C	.03	.00	1	0
10-688	F	1923		01	1942	12	1974	4	B2	0.0	Z9C	.21	.00	11	0
10-689	F	1919		01	1943	26	1974	3	B3	0.0	Z9C	.12	.00	6	0
10-714	F	1908		01	1925	57	1974	0	B6	0.00230	Z4B	.00	.00	0	0
10-725	M	1927		07	1952	1	1973	5	B2	0.0	Z9C	.14	.00	6	0
10-728	F	1923		01	1946	2	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-729	F	1902		06	1920	832	1973	1	B6	0.0	Z9B	.06	.00	4	0
10-730	F	1907		01	1928	260	1974	4	B6	0.0	Z9C	.20	.00	13	0
10-731	M	1921		07	1951	1196	1974	2	B3	0.0	Z9C	.02	.00	1	0
10-732	M	1924		07	1950	1300	1974	0	B6	0.0	Z9C	.01	.00	0	0
10-736	F	1929		01	1948	9	1974	0	B6	0.0	Z9C	.00	.00	0	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
10-738	M	1923		07	1965	6	1974	3	B3	0.0	Z9C	.05	.00	1	0
10-739	F	1931		01	1951	7	1974	1	B6	0.0	Z9C	.02	.00	1	0
10-742	F	1929		07	1946	1	1974	2	B3	0.0	Z9C	.08	.00	4	0
10-744	F	1890		05	1925	0	1975*	120	G4	0.0	Z9	7.31	.00	504	0
10-754	F	1881		05	1925	0	1975*	12	G4	0.0	Z9	.73	.00	50	0
10-850	F	1925		01	1943	0	1974	1	B6	0.0	Z9C	.05	.00	3	0
10-851	F	1921		01	1951	139	1974	0	B6	0.0	Z9B	.00	.00	0	0
10-852	F	1905		01	1923	13	1974	0	B6	0.01300	Z2B	.00	.00	0	0
10-853	F	1919		17	1947	1300	1974	1	B6	0.0	Z9B	.03	.00	1	0
10-854	M	1909		06	1928	104	1974	0	B6	0.0	Z9B	.00	.00	0	0
10-856	F	1952		01	1973	6	1974	1	B6	0.0	Z9C	.01	.00	0	0
10-859	F	1951		07	1973	0	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-860	F	1925		07	1962	7	1974	7	B2	0.0	Z9C	.21	.00	6	0
10-861	F	1954		01	1973	22	1974	1	B6	0.0	Z9C	.01	.00	0	0
10-862	F	1928		01	1946	10	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-864	M	1906		01	1949	1300	1974	1	B6	0.0	Z9C	.01	.00	0	0
10-867	F	1915		07	1929	209	1974	0	B6	0.0	Z9B	.00	.00	0	0
10-869	F	1902		01	1927	132	1974	0	B6	0.0	Z9B	.00	.00	0	0
10-870	F	1911		07	1944	650	1974	0	B6	0.0	Z9B	.00	.00	0	0
10-874	F	1924		01	1942	728	1974	4	B3	0.0	Z9B	.17	.00	8	0
10-880	M	1912		06	1935	156	1974	0	B6	0.0	Z9B	.00	.00	0	0
10-883	F	1883	1935	02	1930	+0	1975*	27	A1	0.0	Z9	.50	.00	8	0
10-890	F	1912		01	1927	2	1974	0	B6	0.00330	Z8B	.00	.00	0	0
10-893	F	1926		01	1943	78	1974	11	B2	0.0	Z9C	.53	.00	27	0
10-894	F	1924		01	1942	38	1974	1	B6	0.0	Z9C	.03	.00	2	0
10-895	F	1925		01	1943	9	1974	2	B3	0.0	Z9C	.07	.00	4	0
10-896	F	1923		01	1941	8	1974	0	B6	0.0	Z9C	.01	.00	1	0
10-897	F	1930		07	1951	208	1975*	3	B6	0.0	Z9C	.11	.00	4	0
10-901	F	1910		01	1924	3	1975*	0	B6	0.01160	Z2B	.00	.00	0	0
10-905	F	1928		01	1946	10	1974	0	B6	0.0	Z9C	.01	.00	0	0
10-907	F	1910		01	1946	5	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-908	F	1928		01	1946	4	1974	1	B6	0.0	Z9C	.05	.00	2	0
10-909	F	1919		01	1941	4	1974	2	B3	0.0	Z9C	.11	.00	6	0
10-911	F	1928		01	1947	2	1974	2	B6	0.0	Z9C	.08	.00	4	0
10-915	F	1931		01	1953	0	1974	1	B6	0.0	Z9C	.03	.00	1	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
10-916	F	1915		01	1946	2	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-919	F	1924		01	1943	8	1974	2	B6	0.0	Z9C	.07	.00	4	0
10-931	M	1911		01	1946	1040	1974	5	B2	0.0	Z9C	.13	.00	5	0
10-932	M	1903		76	1919	208	1974	14	B2	0.0	Z9B	.63	.00	45	0
10-933	F	1924		01	1943	3	1974	2	B6	0.0	Z9C	.09	.00	5	0
10-934	F	1924		01	1948	1196	1974	0	B6	0.0	Z9C	.01	.00	0	0
10-935	M	1925		07	1959	780	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-938	F	1952		01	1971	8	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-940	F	1939		07	1958	4	1974	1	B6	0.0	Z9C	.03	.00	1	0
10-941	F	1928		01	1948	13	1974	1	B6	0.0	Z9C	.03	.00	1	0
10-944	F	1922		01	1951	6	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-945	F	1915		01	1943	12	1974	9	B2	0.0	Z9C	.44	.00	23	0
10-948	F	1923		01	1943	3	1974	0	B6	0.0	Z9C	.02	.00	1	0
10-949	F	1925		01	1943	0	1974	2	B3	0.0	Z9C	.09	.00	5	0
10-950	F	1922		01	1943	1	1974	5	B2	0.0	Z9C	.22	.00	12	0
10-951	F	1916		01	1943	8	1974	1	B6	0.0	Z9C	.03	.00	1	0
10-952	F	1911		01	1927	10	1974	1	B6	0.00329	Z8B	.06	.06	4	4
10-955	F	1922		01	1942	104	1974	1	B6	0.0	Z9B	.05	.00	2	0
10-957	F	1922		01	1941	130	1974	1	B6	0.0	Z9B	.05	.00	3	0
10-958	F	1931		01	1951	13	1975*	3	B3	0.0	Z9C	.13	.00	5	0
10-959	F	1929		01	1946	2	1974	4	B3	0.0	Z9C	.16	.00	8	0
10-963	F	1901		01	1919	10	1975*	647	B1	0.00170	B3B	41.74	63.60	3096	4783
10-966	F	1908		01	1929	4	1974	0	B6	0.0	Z9B	.00	.00	0	0
10-967	F	1924		01	1943	2	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-970	F	1955		07	1973	22	1974	2	B3	0.0	Z9C	.01	.00	0	0
10-971	F	1952		17	1973	22	1975*	1	B6	0.0	Z9C	.01	.00	0	0
10-972	F	1926		01	1947	5	1974	0	B6	0.0	Z9C	.01	.00	1	0
10-974	F	1924		01	1941	48	1974	0	B6	0.0	Z9B	.00	.00	0	0
10-975	F	1929		01	1947	13	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-977	F	1923		01	1943	38	1974	6	B2	0.0	Z9C	.28	.00	14	0
10-978	M	1927		07	1943	1612	1974	4	B3	0.0	Z9C	.06	.00	2	0
10-979	F	1925		01	1943	13	1974	1	B6	0.0	Z9C	.03	.00	2	0
10-980	F	1926		07	1945	1	1974	1	B6	0.0	Z9C	.05	.00	2	0
10-981	F	1928		07	1946	0	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-987	F	1926		01	1946	26	1974	1	B6	0.0	Z9C	.06	.00	3	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
10-988	M	1952	1974	07	1973	22	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-989	F	1927		07	1945	52	1975*	1	B6	0.0	Z9C	.02	.00	1	0
10-990	F	1920		07	1943	20	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-991	M	1901		07	1941	1716	1974	1	B6	0.0	Z9C	.02	.00	1	0
10-992	F	1919		01	1942	39	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-993	F	1904		07	1942	4	1974	0	B6	0.0	Z9C	.00	.00	0	0
10-996	F	1900		07	1943	806	1974	7	G3	0.0	Z9	.28	.00	12	0
10-997	F	1926		07	1945	572	1974	8	G3	0.0	Z9	.33	.00	14	0
10-998	F	1909		07	1942	988	1974	7	G6	0.0	Z9	.27	.00	12	0
11-003	F	1919		07	1942	+0	1974	3	G6	0.0	Z9	.14	.00	8	0
11-004	M	1924		01	1946	702	1974	0	G6	0.0	Z9	.00	.00	0	0
11-005	M	1926		17	1948	520	1974	2	G6	0.0	Z9	.05	.00	2	0
11-009	F	1913		07	1942	884	1974	0	B6	0.0	Z9B	.00	.00	0	0
11-010	F	1922		07	1942	572	1974	0	G6	0.0	Z9	.00	.00	0	0
11-018	F	1908		01	1925	5	1974	0	B6	0.00330	Z8B	.00	.00	0	0
11-023	F	1911		17	1927	2	1975*	0	B6	0.0	Z9B	.00	.00	0	0
11-027	F	1910		71	1948	312	1974	0	G6	0.0	Z9	.00	.00	0	0
11-028	F	1925		01	1944	78	1974	0	B6	0.0	Z9B	.00	.00	0	0
11-030	F	1929		07	1951	112	1975*	4	B3	0.0	Z9B	.16	.00	7	0
11-032	M	1931		06	1956	936	1974	3	B3	0.0	Z9C	.04	.00	1	0
11-033	M	1951		06	1973	104	1975*	0	B6	0.0	Z9C	.00	.00	0	0
11-034	M	1915		06	1934	2080	1974	60	B2	0.0	Z9C	1.12	.00	42	0
11-036	M	1914		07	1946	1456	1974	7	B2	0.0	Z9C	.11	.00	3	0
11-038	M	1914		06	1940	1456	1974	18	B2	0.0	Z9C	.46	.00	18	0
11-040	M	1915		67	1939	1560	1974	6	B3	0.0	Z9C	.14	.00	5	0
11-042	M	1923		07	1946	1456	1974	5	B3	0.0	Z9C	.08	.00	2	0
11-045	M	1915		06	1943	1560	1974	27	B2	0.0	Z9C	.52	.00	17	0
11-049	F	1908		01	1923	13	1975*	0	B6	0.01160	Z2B	.00	.00	0	0
11-056	F	1908		01	1927	40	1974	2	B6	0.0	Z9B	.12	.00	8	0
11-059	F	1925		01	1943	13	1974	0	B6	0.0	Z9B	.00	.00	0	0
11-065	F	1928		07	1943	13	1974	0	B6	0.0	Z9B	.00	.00	0	0
11-070	F	1924		01	1945	26	1974	1	B6	0.0	Z9	.02	.00	1	0
11-071	F	1935		07	1967	2	1974	2	B3	0.0	Z9C	.04	.00	1	0
11-207	M	1917		01	1939	208	1974	0	B6	0.0	Z9B	.00	.00	0	0
11-262	F	1913		01	1933	208	1975*	2	B3	0.0	Z9C	.11	.00	6	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
11-285	F	1915		07	1946	208	1974	0	B6	0.0	Z9C	.00	.00	0	0
11-291	F	1919		17	1951	164	1974	3	B3	0.0	Z9C	.11	.00	4	0
11-294	M	1943		07	1968	6	1974	0	B6	0.0	Z9C	.00	.00	0	0
11-521	F	1910		01	1927	4	1974	0	B6	0.0	Z9C	.00	.00	0	0
11-531	F	1894		01	1918	+0	1975*	3	G6	0.00170	Z5	.20	.34	15	26
11-565	F	1911		01	1927	76	1974	2	B6	0.00330	Z8B	.12	.11	8	8
11-637	M	1902		06	1934	52	1975*	0	B6	0.0	Z9B	.00	.00	0	0
11-916	F	1918		01	1941	108	1975*	1	B6	0.0	Z9B	.05	.00	3	0
11-925	F	1920		01	1941	78	1975*	0	B6	0.0	Z9B	.00	.00	0	0
11-938	F	1931		01	1951	56	1975*	0	B6	0.0	Z9B	.00	.00	0	0
11-947	F	1925		01	1947	260	1975*	4	B3	0.0	Z9B	.17	.00	8	0
11-960	F	1924		01	1942	31	1975*	0	B6	0.0	Z9B	.00	.00	0	0
11-973	F	1919		01	1950	108	1975*	1	B6	0.0	Z9B	.04	.00	2	0
12-025	F	1924		01	1951	182	1975*	1	B6	0.0	Z9C	.04	.00	2	0
12-033	F	1925		07	1950	52	1975*	3	B3	0.0	Z9B	.13	.00	5	0
12-061	F	1920		01	1942	182	1975*	1	B6	0.0	Z9B	.05	.00	2	0
12-089	F	1928		01	1943	52	1974	0	B6	0.0	Z9B	.00	.00	0	0
12-094	F	1929		01	1946	4	1975*	3	B6	0.0	Z9C	.11	.00	6	0
12-095	F	1927		01	1947	1	1974	0	B6	0.0	Z9C	.01	.00	1	0
12-098	F	1930		01	1951	52	1974	1	B6	0.0	Z9C	.03	.00	1	0
12-108	F	1915		01	1943	26	1974	0	B6	0.0	Z9C	.00	.00	0	0
12-111	F	1929		01	1947	19	1974	4	B3	0.0	Z9C	.18	.00	8	0
12-113	F	1915		01	1940	22	1975*	0	B6	0.0	Z9C	.01	.00	1	0
12-115	F	1953		07	1972	52	1975*	0	B6	0.0	Z9C	.00	.00	0	0
12-117	F	1914		01	1943	3	1974	3	B3	0.0	Z9C	.16	.00	8	0
12-119	F	1938		17	1968	52	1975*	1	B6	0.0	Z9C	.02	.00	0	0
12-127	F	1917		01	1941	17	1975*	0	B6	0.0	Z9C	.00	.00	0	0
12-134	F	1927		01	1944	4	1975*	0	B6	0.0	Z9C	.00	.00	0	0
12-136	F	1928		07	1965	30	1975*	1	B6	0.0	Z9C	.02	.00	0	0
12-143	F	1924		01	1941	52	1975*	1	B6	0.0	Z9C	.03	.00	2	0
12-148	F	1925		01	1946	4	1975*	0	B6	0.0	Z9C	.00	.00	0	0
12-163	F	1920		01	1942	78	1974	4	B3	0.0	Z9C	.19	.00	10	0
12-165	F	1917		01	1947	78	1974	3	B3	0.0	Z9C	.15	.00	7	0
12-168	F	1926		01	1946	13	1975*	1	B6	0.0	Z9C	.05	.00	2	0
12-173	F	1930		01	1949	1	1974	2	B3	0.0	Z9C	.08	.00	3	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
12-175	F	1927		01	1946	39	1975*	1	B6	0.0	Z9C	.02	.00	1	0
12-185	F	1920		01	1943	52	1975*	0	B6	0.0	Z9C	.00	.00	0	0
12-186	F	1927		01	1945	4	1974	8	B2	0.0	Z9C	.34	.00	17	0
12-190	F	1927		01	1948	8	1975*	0	B6	0.0	Z9C	.00	.00	0	0
12-193	F	1925		01	1942	1	1974	1	B6	0.0	Z9C	.06	.00	3	0
12-197	F	1906		01	1922	26	1974	1	B6	0.0	Z9C	.04	.00	3	0
12-262	F	1921		01	1942	52	1975*	0	B6	0.0	Z9C	.01	.00	1	0
12-270	F	1919		01	1943	18	1975*	0	B6	0.0	Z9C	.01	.00	0	0
12-304	F	1923		01	1943	52	1975*	0	B6	0.0	Z9C	.00	.00	0	0
12-308	F	1900		01	1942	52	1975*	2	B3	0.0	Z9C	.10	.00	5	0
12-330	M	1928		07	1944	63	1974	1	B6	0.0	Z9B	.03	.00	2	0
12-331	M	1930		07	1944	65	1974	0	B6	0.0	Z9B	.00	.00	0	0
12-333	M	1932		06	1955	728	1974	3	B3	0.0	Z9C	.06	.00	2	0
12-334	F	1908		01	1924	17	1975*	4	B3	0.0	Z9C	.26	.00	18	0
12-343	F	1900		07	1918	208	1974	0	G6	0.01375	Z2	.00	.00	0	0
12-344	F	1908		07	1930	104	1974	0	B6	0.0	Z9B	.00	.00	0	0
12-346	F	1908		01	1926	3	1975*	3	B3	0.0	Z9C	.19	.00	13	0
12-349	F	1940		07	1961	156	1974	1	B6	0.0	Z9C	.02	.00	1	0
12-350	F	1906		01	1923	39	1974	1	B6	0.0	Z9C	.07	.00	5	0
12-352	F	1906		06	1923	416	1975*	1	B6	0.0	Z9C	.07	.00	5	0
12-364	F	1927		01	1968	364	1975*	1	B6	0.0	Z9C	.01	.00	0	0
12-365	F	1931		01	1952	520	1975*	1	B6	0.0	Z9	.02	.00	1	0
12-368	F	1923		01	1958	884	1975*	2	C6	0.0	Z9C	.03	.00	1	0
12-370	F	1908		07	1924	104	1974	0	B6	0.0	Z9B	.00	.00	0	0
12-375	F	1917		01	1958	312	1975*	0	B6	0.0	Z9C	.00	.00	0	0
12-377	F	1920		01	1961	676	1975*	0	B6	0.0	Z9C	.00	.00	0	0
12-397	M	1916		06	1947	520	1975*	28	B2	0.0	Z9B	.81	.00	34	0
12-422	F	1907		01	1937	39	1975*	0	B6	0.0	Z9B	.00	.00	0	0
12-425	M	1938		07	1960	6	1975*	0	B6	0.0	Z9B	.00	.00	0	0
12-426	M	1923		07	1946	18	1975*	1	B6	0.0	Z9B	.03	.00	2	0
12-428	F	1907		01	1922	13	1975*	186	B2	0.0	Z9C	11.65	.00	833	0
12-429	F	1922		01	1945	13	1975*	0	B6	0.0	Z9C	.00	.00	0	0
12-430	F	1927		01	1941	26	1975*	1	B6	0.0	Z9C	.03	.00	2	0
12-436	F	1896		01	1918	26	1975*	1	B6	0.0	Z9C	.05	.00	3	0
12-437	F	1926		01	1943	104	1975*	1	B6	0.0	Z9C	.07	.00	3	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1975

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 NCI/G	(14) INPUT RA228 NCI/G	(15) CUM RADS RA226	(16) CUM RADS RA228
12-460	M	1923		17	1945	1092	1975*	0	B6	0.0	Z9B	.00	.00	0	0
12-499	F	1908		01	1925	8	1975*	2	C6	0.0	Z9C	.11	.00	8	0
12-502	F	1924		01	1945	13	1975*	0	B6	0.0	Z9C	.00	.00	0	0
12-508	F	1937		17	1957	884	1975*	0	B6	0.0	Z9C	.01	.00	0	0
12-532	M	1905		17	1929	2132	1975*	1	B6	0.0	Z9C	.02	.00	1	0
12-533	F	1952		07	1970	260	1975*	2	B6	0.0	Z9C	.01	.00	0	0
12-544	F	1921		01	1941	534	1975*	4	B3	0.0	Z9B	.18	.00	9	0
12-545	F	1920		01	1937	902	1975*	11	B2	0.0	Z9B	.50	.00	24	0
12-547	F	1918		01	1942	1508	1975*	3	B3	0.0	Z9B	.10	.00	3	0
12-548	F	1919		17	1939	832	1975*	1	B6	0.0	Z9B	.04	.00	2	0
12-549	F	1917		01	1943	604	1975*	2	B6	0.0	Z9B	.09	.00	4	0
12-561	F	1917		16	1942	243	1975*	0	B6	0.0	Z9B	.00	.00	0	0

APPENDIX B. Radium-Induced Malignancies

Measured Persons

Tables 1 and 2 summarize measured radium cases considered to have radium-induced bone sarcomas and paranasal sinus or mastoid carcinomas, respectively. The cases are listed in order of skeletal dose, from both ^{226}Ra and ^{228}Ra, accumulated to the date of diagnosis of the tumor or to the date of death if there was no diagnosis before death. Detailed exposure and dosimetric data for these cases can be found in Table 1 of Appendix A of this report.

There are 55 bone sarcoma cases and 27 sinus or mastoid carcinoma cases among the 1832 persons whose body burdens of radium have been measured. Five persons had both types of tumor (cases 01-179, 03-110, 03-402, 03-429, and 03-648) so that there are 77 measured persons considered to have radium-induced malignancies. There is one more case (01-051) in Table 1 than appeared in the corresponding table in the 1975 annual report.[1] At the time of a mid-thigh amputation of the left leg of this case in 1972, microscopic examination of tumor tissue from the left distal tibia was interpreted to show a plasma cell tumor (myeloma), but a recent histologic review of the slides of this tumor tissue at the Center for Human Radiobiology resulted in a diagnosis of osteogenic sarcoma. No new cases of paranasal sinus or mastoid carcinoma in a measured person came to our attention in the year 1975.

Unmeasured Cases

Tables 3 and 4 list exposed persons with unknown or uncertain radium body content who had probable or confirmed bone sarcomas and probable or confirmed paranasal sinus or mastoid carcinomas, respectively. There are 27 probable or confirmed bone sarcoma cases and 5 probable or confirmed sinus or mastoid carcinoma cases among the approximately 1300 radium cases with unmeasured body burdens for whom medical data are available. We have evidence that 11 of these "unmeasured" persons had early radioactivity measurements which were interpreted to show a positive indication of radium in the body; work is in progress to estimate lower limits of radium content for these cases.

TABLE 1. Bone Sarcomas in Persons with Known Radium Body Content as of 31 December 1975.

CASE	SEX	BORN	DIED	EXPOSED	CUM.RADS	DIAGNOSED
00-003	F	1894	1927	1917	44441	1927
01-079	F	1901	1943	1920	21115	1942
01-032	F	1908	1940	1924	18248	1940
01-033	F	1908	1931	1923	18023	1930
03-584	F	1905	1959	1923	16821	1958
03-648	F	1903	1956	1922	16713	1956
01-009	F	1898	1945	1918	14306	1944
03-213	F	1892	1955	1925	14049	1954
01-105	F	1898	1945	1921	12555	1945
05-215	F	1886	1968	1917	12073	1960
00-006	F	1903	1930	1918	11760	1930
03-671	F	1906	1953	1922	11314	1952
01-046	F	1903	1943	1920	11190	1942
00-004	F	1900	1931	1917	11063	1930
00-028	F	1902	1933	1917	10265	1930
01-172	F	1898	1968	1916	9628	1968
03-201	F	1909	1963	1922	9586	1962
01-389	F	1910	1930	1923	9507	1930
01-562	F	1901	1931	1920	7143	1931
03-215	M	1896	1971	1925	6860	1957
03-401	F	1900	1963	1923	6781	1962
00-005	F	1901	1939	1917	6643	1939
01-031	F	1906	1934	1925	6331	1934
03-619	F	1903	1962	1922	6184	1962
01-007	F	1886	1949	1926	5972	1948
01-059	F	1905	1967	1920	5182	1962
01-011	F	1872	1937	1919	5175	1936
03-118	F	1898	1955	1931	5159	1955
00-007	F	1903	1935	1919	5046	1934
00-027	F	1902	1942	1918	4995	1942
03-429	F	1908	L	1923	4387	1967
01-051	F	1904	L	1923	4266	1972
05-281	F	1898	1964	1916	4142	1956
03-234	F	1890	1965	1915	3810	1964
03-402	F	1905	L	1923	3761	1953
01-024	F	1901	1956	1919	3674	1956
01-179	F	1890	1966	1924	3642	1943
01-239	F	1901	1958	1917	3153	1955
01-520	F	1882	1969	1930	3132	1967
01-073	F	1900	1969	1921	3048	1969
01-099	F	1905	1945	1924	2923	1942
01-026	F	1905	1958	1925	2729	1955
03-649	F	1906	1954	1924	2664	1953
01-025	F	1886	1952	1924	2654	1950
01-613	F	1906	1936	1923	2436	1936

TABLE 1. (Cont'd)

CASE	SEX	BORN	DIED	EXPOSED	CUM.RADS	DIAGNOSED
03-212	F	1902	1951	1927	2412	1951
03-210	M	1906	1958	1926	2396	1956
01-268	F	1901	1968	1917	2249	1959
03-209	M	1894	1960	1925	1698	1958
03-216	F	1907	1961	1922	1606	1959
01-112	F	1908	1955	1924	1547	1954
03-227	F	1878	1952	1930	1470	1949
03-110	F	1899	1967	1931	1467	1963
03-455	F	1906	L	1922	1445	1934
01-439	F	1880	1953	1922	888	1949

TABLE 2. Carcinomas of the Paranasal Sinuses and Mastoid Air Cells in Persons with Known Radium Body Content as of 31 December 1975.

CASE	SEX	BORN	DIED	EXPOSED	CUM.RADS	DIAGNOSED
01-145	F	1900	1957	1918	25701	1957
01-008	F	1900	1958	1917	22309	1958
01-149	F	1888	1959	1919	20067	1958
03-648	F	1903	1956	1922	16455	1955
03-232	F	1898	1957	1917	14736	1956
01-006	F	1899	1938	1919	8505	1938
03-240	F	1916	1955	1930	7655	1953
03-206	M	1914	1975	1936	7056	1974
01-014	F	1901	1949	1916	6799	1949
01-179	F	1890	1966	1924	6019	1965
03-429	F	1908	L	1923	4783	1973
03-402	F	1905	L	1923	4596	1964
03-101	F	1908	1971	1931	4448	1970
01-171	M	1895	1975	1914	4311	1966
03-407	F	1905	1961	1923	4206	1959
03-214	F	1895	1966	1925	3964	1959
03-235	F	1900	1968	1928	3803	1965
03-126	F	1910	1965	1931	3449	1965
01-573	F	1892	1945	1916	3307	1945
03-105	M	1903	1957	1931	3143	1957
03-423	F	1907	1972	1923	2036	1971
03-417*	F	1909	1966	1924	1894	1962
03-141	M	1906	1963	1933	1550	1963
01-022	F	1900	1951	1917	1544	1951
03-110	F	1899	1967	1931	1467	1963
05-284	F	1899	1973	1919	1179	1970
03-488	F	1907	1975	1922	605	1973

* Carcinoma of Case 03-417 apparently arose in R. gingiva (posterior maxilla).

Table 3. Probable or Confirmed Bone Sarcomas in Exposed Persons† with Unknown or Uncertain Radium Body Content.

Case	Sex	Born	Died	Exposed	Diagnosed
00-011	F	1896	1936	1917	1935
00-013	F	1899	1933	1917	1933
00-019	F	1895	1946	1917	1946
00-023	F	1900	1929	1917	1929
00-030	F	1903	1924	1918	1923
00-031	F	1903	1940	1921	1938
00-035	F	1900	1941	1917	1941
01-088	F	1906	1931	1923	1931
01-103	F	1903	1946	1922	1946
01-107	F	1909	1935	1923	1935
01-108	F	1908	1947	1924	1947
01-117	F	1907	1931	1922	1931
01-387	F	1895	1943	1918	1943
01-465	M	1881	1943	1925	1943
01-695	F	1908	1935	1923	1935
03-658	F	1903	1938	1922	1938
03-660	F	1907	1936	1923	1935
03-661	F	1906	1934	1922	1934
03-665	F	1909	1930	1924	1929
03-680	F	1906	1946	1924	1943
03-759	F	1904	1930	1924	1930
03-779	F	1905	1942	1922	1942
03-800	F	1908	1945	1924	1945
03-806	F	1896	1956	1922	1956
03-848	F	1903	1958	1922	1958
05-987	F	1901	1962	1918	1962
09-087	M	1891	1934	1912	1934

† All were dial painters, except Cases 01-387 (iatrogenic, i.v. and oral), 01-465 (drank Radithor), and 09-087 (chemist).

Table 4. Probable or Confirmed Carcinomas of the Paranasal Sinuses and Mastoid Air Cells in Exposed Persons† with Unknown or Uncertain Radium Body Content.

Case	Sex	Born	Died	Exposed	Diagnosed
01-587	F	1894	1943	1919	1943
03-675[a]	F	1896	1960	1922	1959
03-760	F	1907	1946	1924	1946
03-772	F	1904	1953	1922	1953
03-785	F	1903	1955	1925	1953

a. Death Certificate lists paranasal sinus carcinoma as cause of death; diagnoses from histology of biopsy tissue were myosarcoma or liposarcoma of the maxillary antrum.

† All were dial painters.

Reference

1. Radium-induced malignancies, Radiological and Environmental Research Division Annual Report, July 1974–June 1975, ANL-75-60, Part II, pp. 207–210.

PUBLICATIONS BY THE STAFF OF THE CENTER FOR HUMAN RADIOBIOLOGY FOR THE PERIOD JULY 1975 THROUGH JUNE 1976

A. M. Brues, The use of animal data in derivation of standards, Health Phys. 29, 521–524 (October 1975).

Austin M. Brues, Malignancies in patients contaminated with radium, The Health Effects of Plutonium and Radium, Proc. Symp. Sun Valley, Idaho, 6–9 October 1975, W. S. S. Jee, Ed., The J. W. Press, Salt Lake City, Utah, pp. 451–455 (1976).

S. F. Hoegerman, The cytogenetic effects of internal alpha emitters on human lymphocytes: A review, The Health Effects of Plutonium and Radium, Proc. Symp. Sun Valley, Idaho, 6–9 October 1975, W. S. S. Jee, Ed., The J. W. Press, Salt Lake City, Utah, pp. 779–791 (1976).

R. B. Holtzman and D. J. Simmons, The macrodistribution of ^{226}Ra in the skeleton of a radium dial painter, The Health Effects of Plutonium and Radium, Proc. Symp. Sun Valley, Idaho, 6–9 October 1975, W. S. S. Jee, Ed., The J. W. Press, Salt Lake City, Utah, pp. 421–436 (1976).

A. T. Keane, Fractional decay of thoron in the collection chamber and in the lines leading to the chamber, under the assumption of uniform mixing of the flow gas, Appendix I, Biological and Environmental Effects of Low-Level Radiation, Proc. Symp. Chicago, 3–7 November 1975, Int. Atomic Energy Agency, Vienna, Vol. II, pp. 193–195 (1976).

Donald J. Keefe, William P. McDowell, and Peter G. Groer, Use of a microprocessor in a remote working level monitor, IEEE Trans. Nucl. Sci. NS-23, 704 (February 1976).

D. B. Kimmel, W. S. S. Jee, T. J. Wronski, R. A. Schlenker, and B. J. Stover, A morphometric and autoradiographic study of the ulna and second lumbar vertebral body of young adult beagles, The Health Effects of Plutonium and Radium, Proc. Symp. Sun Valley, Idaho, 6–9 October 1975, W. S. S. Jee, Ed., The J. W. Press, Salt Lake City, Utah , pp. 105–126 (1976).

Dorothy R. Kuchta, J. Rundo, and R. B. Holtzman, Low-level determination of skeletal ^{228}Ra and ^{228}Th in the presence of gross amounts of ^{226}Ra, Biological and Environmental Effects of Low-Level Radiation, Proc. Symp. Chicago, 3–7 November 1975, Int. Atomic Energy Agency, Vienna, Vol. II, pp. 183–196 (1976).

R. P. Larsen and R. D. Oldham, Anion-exchange separation of plutonium in hydrochloric-hydrobromic acid media, Talanta 22, 577–580 (September 1975).

R. P. Larsen, R. E. Toohey, and F. H. Ilcewicz, Macrodistribution of plutonium in selected bones from an abnormal skeleton, The Health Effects of Plutonium and Radium, Proc. Symp. Sun Valley, Idaho, 6–9 October 1975, W. S. S. Jee, Ed., The J. W. Press, Salt Lake City, Utah, pp. 315–320 (1976).

E. L. Lloyd, M. Menon, and J. L. Mitchen, Cell mediated immunity as an early diagnostic test for osteosarcoma in human radium cases, Radiation and the Lymphatic System, Proc. 14th Ann. Hanford Biology Symposium, Richland, Washington, 30 September–2 October 1974, U.S. ERDA Report No. CONF-740930, pp. 165–168 (1975).

E. L. Lloyd, J. F. Loutit, and F. Mackevicius, Viruses in osteosarcomas induced by ^{226}Ra: A study of the induction of bone tumors in mice, Int. J. Radiat. Biol. 28 (1), 13–33 (October 1975).

E. L. Lloyd and M. Menon, Immunological studies in the human radium population, The Health Effects of Plutonium and Radium, Proc. Symp. Sun Valley, Idaho, 6–9 October 1975, W. S. S. Jee, Ed., The J. W. Press, Salt Lake City, Utah, pp. 485–496 (1976).

J. H. Marshall and P. G. Groer, A theory of the induction of bone cancer by alpha radiation: A summary, The Health Effects of Plutonium and Radium, Proc. Symp. Sun Valley, Idaho, 6–9 October 1975, W.S.S. Jee, Ed., The J. W. Press, Salt Lake City, Utah, pp. 717–728 (1976).

NCRP Scientific Committee 43 on Natural Background Radiation (John H. Harley, Chairman, Richard B. Holtzman, Wayne M. Lowder, Dade W. Moeller, Allan B. Tanner, and Ned A. Wogman), Natural background radiation in the United States; Recommendations of the National Council on Radiation Protection and Measurements, Nat. Counc. on Radiation Protection and Measurements, Washington, D.C. (November 1975).

R. E. Rowland, The risk of malignancy from internally-deposited radioisotopes, Radiation Research: Biomedical, Chemical, and Physical Perspectives, Proc. Fifth Int. Cong. of Radiation Research, Seattle, 14–20 July 1974, O. F. Nygaard, H. I. Adler, and W. K. Sinclair, Eds., Academic Press, Inc., New York, pp. 146–155 (1975).

R. E. Rowland and P. W. Durbin, Survival, causes of death, and estimated tissue doses in a group of human beings injected with plutonium, The Health Effects of Plutonium and Radium, Proc. Symp. Sun Valley, Idaho, 6–9 October 1975, W. S. S. Jee, Ed., The J. W. Press, Salt Lake City, Utah, pp. 329–342 (1976).

J. Rundo, Review of "In vivo neutron activation analysis, Proceedings of a Panel, Vienna, 17–21 April 1972, Int. Atomic Energy Agency, Vienna, 1973," Health Phys. 29, 891 (December 1975).

J. Rundo, P. M. Starzyk, J. Sedlet, R. P. Larsen, R. D. Oldham, and J. J. Robinson, The excretion rate and retention of plutonium 10 000 days after acquisition, Diagnosis and Treatment of Incorporated Radionuclides, Proc. Seminar, Vienna, 8–12 December 1975, Int. Atomic Energy Agency, Vienna, pp. 15–22 (1976).

J. Rundo and R. B. Holtzman, Comparison of the late excretion of ^{226}Ra and ^{239}Pu by man, The Health Effects of Plutonium and Radium, Proc. Symp. Sun Valley, Idaho, 6–9 October 1975, W. S. S. Jee, Ed., The J. W. Press, Salt Lake City, Utah, pp. 497–504 (1976).

J. Rundo, M. A. Essling, and D. R. Huff, Gross distribution of ^{226}Ra in man from external counting, The Health Effects of Plutonium and Radium, Proc. Symp. Sun Valley, Idaho, 6–9 October 1975, W. S. S. Jee, Ed., The J. W. Press, Salt Lake City, Utah, pp. 409–420 (1976).

R. A. Schlenker and J. H. Marshall, Thicknesses of the deposits of plutonium and radium at bone surfaces in the beagle, Health Phys. 29, 649–654 (November 1975).

Robert A. Schlenker, Billie G. Oltman, and Helen T. Cummins, Microscopic distribution of ^{239}Pu deposited in bone from a human injection case, The Health Effects of Plutonium and Radium, Proc. Symp. Sun Valley, Idaho, 6–9 October 1975, W. S. S. Jee, Ed., The J. W. Press, Salt Lake City, Utah, pp. 321–328 (1976).

R. A. Schlenker and J. E. Farnham, Microscopic distribution of ^{226}Ra in the bone of radium cases: A comparison between diffuse and average ^{226}Ra concentrations, The Health Effects of Plutonium and Radium, Proc. Symp. Sun Valley, Idaho, 6–9 October 1975, W. S. S. Jee, Ed., The J. W. Press, Salt Lake City, Utah, pp. 437–450 (1976).

R. A. Schlenker, B. G. Oltman, and T. J. Kotek, Bone mineral mass and width in normal white women and men, J. Roentgenol. 126 (6), 1282–1283 (June 1976).

R. A. Schlenker and W. W. VonSeggen, The distribution of cortical and trabecular bone mass along the lengths of the radius and ulna and the implications for in vivo bone mass measurements, Calcif. Tiss. Res. 20, 41–52, (1976).

Robert A. Schlenker, Percentages of cortical and trabecular bone in the radius and ulna, Am. J. Roentgenol. 126, 1309–1312 (1976).

D. J. Simmons, A. T. Keane, R. B. Holtzman, and J. H. Marshall, Plugged Haversian canals and skeletal dose in radium cases, Health Phys. 29, 767–775 (November 1975).

R. E. Toohey, An experimental method of estimating the depth of ^{241}Am deposited in the chest, Program of the 20th Bioassay, Environmental, and Analytical Chemistry Conf., Cincinnati, 24–25 September 1974, Paper published in Health Phys. 29, 417–418 (September 1975).

R. E. Toohey and J. Rundo, A rapid method for estimating the effective depth of internally deposited Americium-241, Diagnosis and Treatment of Incorporated Radionuclides, Proc. Seminar, Vienna, 8-12, December 1975. Int. Atomic Energy Agency, Vienna, pp. 277–284 (1976).

R. E. Toohey and M. A. Essling, Gross distribution of ^{241}Am in a man seven years after inhalation, Biological and Environmental Effects of Low-Level Radiation, Proc. IAEA Symp., Chicago, 3–7 November 1975, Int. Atomic Energy Agency, Vienna, Vol. II, pp. 153–160 (1976).

Wayne VonSeggen, Robert A. Schlenker, and Joseph A. Farnham, Weakening of bone by osteolytic lesions in a radium case, Health Phys. 30, 243–245 (February 1976).

ACCEPTED FOR PUBLICATION

A. M. Brues, The fate of patients containing radium, Trans. Am. Clin. Climatol. Assoc.

R. D. Lloyd and J. Rundo, "Half-life" terminology for ^{137}Cs in humans, Health Phys.

Peter G. Groer and John H. Marshall, A model for the induction of bone cancer by ^{224}Ra, Second Int. Symp. on Biological Effects of ^{224}Ra: Benefit and Risk of Therapeutic Application, Commission of European Communities, at München-Neuherberg, Germany, 20–21 September 1976. Proc. to be published in Strahlentherapie.

J. H. Marshall, P. G. Groer, and R. A. Schlenker, The dose to endosteal cells from radium-224, Final program and preliminary abstracts of the Int. Symp. on Biological Effects of Injected ^{224}Ra (ThX) and Thorotrast, Alta, Utah, 21–23 July 1974, Abstract No. 9. Proc. to be published in Health Phys.

William P. McDowell, D. J. Keefe, P. G. Groer, and R. T. Witek, A microprocessor-assisted calibration for a remote working level monitor, 1976 Nuclear Science Symp. and Scintillation and Semiconductor Counter Symp., Nuclear and Plasma Sciences Society of the Institute of Electrical and Electronics Engineers, New Orleans, 20–22 October 1976. Proc. to be published in IEEE Trans. Nucl. Sci.

D. Newton, J. Rundo, and G. E. Harrison, The retention of alkaline earth elements in man, with special reference to barium, Health Phys.

A. P. Polednak, Adult height and weight of female radium dial workers, with analysis of radiation effect on growth, Human Biology.

A. P. Polednak, Long-term effects of radium exposure in female dial workers: Hematocrit and blood pressure, Environmental Res.

R. E. Rowland, A. F. Stehney, A. M. Brues, M. S. Littman, A. T. Keane, and B. C. Patten, Current status of the study of ^{226}Ra and ^{228}Ra in humans at the Center for Human Radiobiology, Final program and preliminary abstracts of the Int. Symp. on Biological Effects of Injected ^{224}Ra (ThX) and Thorotrast, Alta, Utah, 21–23 July 1974, Abstract No. 16. Paper to be published in Health Phys.

J. Rundo, The radioactive properties and biological behaviour of ^{224}Ra (ThX) and its daughters, Final program and preliminary abstracts of the Int. Symp. on Biological Effects of Injected ^{224}Ra (ThX) and Thorotrast, Alta, Utah, 21–23 July 1974, Abstract No. 1. Paper to be published in Health Phys.

Herta Spencer, Richard B. Holtzman, Lois Kramer, and Frank H. Ilcewicz, Metabolic balances of ^{210}Pb and ^{210}Po at natural levels, Radiat. Res.

DISTRIBUTION

Internal Distribution

ANL Contract Copy
TIS copies (6)
Library (4)
A. B. Krisciunas (15)
T. E. O'Connor (12)
President AUA
L. Burris
E. J. Croke
P. M. Failla
W. Fairman
M. Fieldhouse
P. R. Fields
B. R. T. Frost
P. F. Gustafson
M. Kanter
S. A. Miller
M. H. Momeni
M. V. Nevitt
D. P. O'Neil
E. N. Pettitt
E. G. Pewitt
R. J. Royston
O. C. Simpson
W. K. Sinclair
R. G. Staker
RER Division (114)
J. L. Andorcon
G. A. Anast
P. A. Brien
A. M. Brues
L. M. Carr
F. R. Clark
C. D. Croft
H. T. Cummins
J. L. Dehmer
P. M. Dehmer
M. Edack
D. N. Edgington
M. Essling
J. E. Farnham
P. Frenzen
S. A. Fry
M. A. Gemmell
C. Graul
P. G. Groer
G. J. Hamilton
D. R. Hamrin
M. J. Harris
C. B. Henning
B. B. Hicks
R. B. Holtzman
R. H. Huebner
D. R. Huff
M. Inokuti
A. T. Keane
Y.-K. Kim
I. E. Kirsh
G. A. Kokaisl
K. P. Konicki
T. J. Kotek
G. Knasko
D. R. Kuchta
R. P. Larsen
N. A. Leventry
M. S. Littman
E. L. Lloyd
H. F. Lucas, Jr.
F. Markun
J. H. Marshall
H. A. May
R. D. Oldham
B. G. Oltman
J. Pan
B. C. Patten
J. C. Person
N. J. Plondke
A. P. Polednak
R. E. Rowland
J. Rundo
R. A. Schlenker
H. A. Schultz
J. Y. Sha
D. Spence
A. F. Stehney
O. J. Steingraber
E. G. Thompson
F. E. Throw
R. E. Toohey
J. M. Tutskey
B. J. Waller
C. A. Yack

External Distribution

ERDA-TIC for distribution per UC-48 (178)
Chicago Patent Group
Manager, ERDA-CH
J. L. Liverman, U. S. ERDA
CHR Advisory Committee:
- R. D. Evans, Scottsdale, Arizona
- L. H. Hempelmann, Strong Memorial Hospital, Rochester, New York
- G. B. Hutchison, Harvard School of Public Health, Boston, Massachusetts
- C. R. Richmond, Oak Ridge National Laboratory, Oak Ridge, Tennessee
- A. C. Upton, State University of New York at Stony Brook, Stony Brook, New York

Radiological and Environmental Research Division Review Committee:
- F. I. Badgley, University of Washington, Seattle, Washington
- R. S. Berry, University of Chicago, Chicago, Illinois
- E. D. Goldberg, Scripps Institution of Oceanography, La Jolla, California
- G. H. Lauff, W. K. Kellogg Biological Station, Hickory Corners, Michigan
- W. F. Neuman, University of Rochester, Rochester, New York
- E. L. Saenger, Cincinnati General Hospital, Cincinnati, Ohio
- F. T. Smith, Stanford Research Institute, Menlo Park, California
- W. H. Smith, Yale University, New Haven, Connecticut

AUA Biology Representatives:
- S. Abrahamson, University of Wisconsin, Madison, Wisconsin
- W. C. Ashby, Southern Illinois University, Carbondale, Illinois
- R. S. Caldecott, University of Minnesota, St. Paul, Minnesota
- W. Chavin, Wayne State University, Detroit, Michigan
- J. Courtright, Marquette University, Milwaukee, Wisconsin
- W. F. Danforth, Illinois Institute of Technology, Chicago, Illinois
- H. S. Ducoff, University of Illinois, Urbana, Illinois
- A. Eisenstark, University of Missouri, Columbia, Missouri
- D. Feir, Saint Louis University, Saint Louis, Missouri
- D. L. Hartl, Purdue University, Lafayette, Indiana
- B. H. Judd, University of Texas at Austin, Austin, Texas
- A. L. Koch, Indiana University, Bloomington, Indiana
- J. C. Loper, University of Cincinnati, Cincinnati, Ohio
- W. R. Martin, University of Chicago, Chicago, Illinois
- H. J. McDonald, Loyola University Medical Center, Maywood, Illinois
- R. P. McIntosh, University of Notre Dame, Notre Dame, Indiana
- W. C. Myser, Ohio State University, Columbus, Ohio
- R. R. Novales, Northwestern University, Evanston, Illinois
- J. W. Osborne, University of Iowa, Iowa City, Iowa
- R. J. Perkins, University of Kansas, Lawrence, Kansas
- R. J. Robel, Kansas State University, Manhattan, Kansas
- R. C. Rustad, Case Western Reserve University, Cleveland, Ohio
- S. Silver, Washington University, Saint Louis, Missouri
- E. A. Stull, University of Arizona, Tucson, Arizona

A. S. Sussman, University of Michigan, Ann Arbor, Michigan
P. W. Todd, Pennsylvania State University, University Park, Pennsylvania
M. J. Ulmer, Iowa State University, Ames, Iowa
I. Ungar, Ohio University, Athens, Ohio
J. J. Wolken, Mellon Institute, Pittsburgh, Pennsylvania
L. Wolterink, Michigan State University, East Lansing, Michigan

Argersinger, W. J., University of Kansas
Arkansas, University of, Medical Center Library, Little Rock
Bielitz, A. M., MIT, Cambridge, Massachusetts
Blahd, W. H., Vet. Admin. Center, Los Angeles, California
Brill, A. B., Vanderbilt Univ., Nashville, Tennessee
Bruckner, B. H., USHEW, Rockville, Maryland
S. R. Bull, University of Missouri, Columbia, Missouri
Burnstein, R. A., IIT, Chicago, Illinois
Burr, J. G., University of Oklahoma, Norman, Oklahoma
Burr, W. W., USERDA, Washington, D. C.
Burtsavage, E. M., Shiremanstown, Pennsylvania
Bustad, L. K., Washingtin State University, Pullman, Washington
Chalfen, M. H., MIT, Cambridge, Massachusetts
Christian, J. E., Purdue University, Lafayette, Indiana
Clark, R. K., Hamilton, Ohio
Cochran, R. G., Texas A & M University, College Station, Texas
Cohen, N., New York University, New York, New York
Cohn, S. H., Brookhaven Natl. Lab., Upton, Long Island, New York
Cole, A. L., Bowman-Gray School of Medicine, Winston-Salem, North Carolina
Collins, P. A., Nathan Goldblatt Memorial Hospital, Chicago, Illinois
Congel, F. J., Macalester College, St. Paul, Minnesota
Cornell University Library, Geneva, New York
Cooper, J., New York City, New York, New York
Costello, M., MIT, Cambridge, Massachusetts
Cummings, J. A., Wisconsin State University
Dohm, G. C. A., Westbury, New York
Durso, M. P., HASL, New York, New York
Edmund, C. E., Milwaukee, Wisconsin
Ellett, W. H., USEPA
Elnaggar, A., Brookhaven National Laboratory, Upton, Long Island, New York
Finkel, A. J., AMA, Chicago, Illinois
Fore, C. S., Oak Ridge National Laboratory, Oak Ridge, Tennessee
Fredregill, C., University of Houston Libraries, Houston, Texas
Goldman, M., University of California, Davis, California
Gottschalk, A., Yale University, New Haven, Connecticut
Griem, M. L., Billings Hospital, Chicago, Illinois
Grunewald, R., University of Wisconsin, Milwaukee, Wisconsin
Gustafson, J. M., University of Chicago, Chicago, Illinois
Hackett, A. J., Naval Biomedical Research Laboratory, Oakland, California
Harley, N., New York University, New York, New York

Harper, P. V., University of Chicago, Chicago, Illinois
Hoegerman, S. F., William & Mary College, Williamsburg, Virginia
Illinois, University of, Library, Chicago, Illinois
Jee, W. S. S., University of Utah, Salt Lake City, Utah
Jowsey, J., Mayo Clinic, Rochester, Minnesota
Kessler, W. V., Purdue University, Lafayette, Indiana
Klappenbach, E. W., USEPA, Chicago, Illinois
Lambert, P. B., Duke Power Company
Landau, R. L., University of Chicago, Chicago, Illinois
LeRoy, G. V., University of Chicago, Chicago, Illinois
Lieben, J., Philadelphia, Pennsylvania
Lin, J. W., Chicago Dept. of Environmental Control, Chicago, Illinois
Lisco, H., Harvard Medical School, Cambridge, Massachusetts
Lohr, L. L., University of Michigan, Ann Arbor, Michigan
Lowden, A., Nuclear-Chicago Corp.
Maletskos, C. J., MIT, Cambridge, Massachusetts
Manber, M., Medical World News
Marks, S., Battelle Northwest Labs., Richland, Washington
Martell, E. A., NCAR, Boulder, Colorado
Mayo Clinic Library
Mays, C. W., University of Utah, Salt Lake City, Utah
McKelvie, D. N., Colorado State University, Fort Collins, Colorado
Meer, R., Massachusetts General Hospital
Michigan Technological University Library, Houghton, Michigan
Moeller, D. W., Kresge Center for Environmental Health, Boston, Massachusetts
Morris, J. P., MIT, Cambridge, Massachusetts
Moseley, R. D., University of New Mexico Medical School, Albuquerque, New Mexico
Murphy, G., Iowa State University, Ames, Iowa
Myers, W. G., Ohio State University Hospital, Columbus, Ohio
Naismith, D. P., University of North Dakota, Grand Forks, North Dakota
NAS Committee on Atomic Casualties
NCAR, Boulder, Colorado
Naunton, R. F., Billings Hospital, Chicago, Illinois
Ney, W. R., NCRP, Washington, D. C.
Nichols, G., Boston, Massachusetts
Nicholson, W. L., Battelle Pacific Labs., Richland, Washington
Ohanian, M. J., University of Florida, Gainesville, Florida
Orvis, A. L., Mayo Clinic, Rochester, Minnesota
Pearson, J. E., University of Illinois, Urbana, Illinois
Pool, M. L., Ohio State University, Columbus, Ohio
Rabinowitz, S., Brooklyn, New York
Robertson, J. S., Mayo Clinic, Rochester, Minnesota
Rossi, H. H., Columbia, New York, New York
Rubnitz, M. E., Hines Hospital, Hines, Illinois
Rust, J. H., University of Chicago, Chicago, Illinois
Scheibner, H., Advertising & Marketing Research Library, Los Angeles, California

Sella, F., United Nations, New York, New York
Shanahan, M. M., Phoenix, Arizona
Sharpe, W. D., East Orange, New Jersey
Shriffine, University of California, Davis, California
Simmons, D. J., Washington University, St. Louis, Missouri
Singh, H. P., Savannah State College, Savannah, Georgia
Smathers, J. B., Texas A & M University, College Station, Texas
Spencer, H., Hines Hospital, Hines, Illinois
Sterner, J. H., University of California, Irvina, California
Stover, B. J., University of North Carolina, Chapel Hill, North Carolina
Taylor, L. S., NBS, Bethesda, Maryland
Thomas, J., Kings County Hospital Center, New York
Varney, D., Eastern Kentucky University, Richmond, Kentucky
Vesselinovitch, S. D., University of Chicago, Chicago, Illinois
Williams, R. H., University of Michigan, Ann Arbor, Michigan
Wrenn, M. F., New York University Medical Center, New York, New York
Beninson, D. J., Commission Nacional de la Energia Atomica, Buenos Aires, Argentina
Comision Nacional de Energia Atomica, Library, Argentina
Cancer Institute Library, Melbourne, Australia
Dudley, R. A., IAEA, Vienna, Austria
Parr, R. M., IAEA, Vienna, Austria
Debois, J. M., St. Norbertus Hospital, Duffel, Belgium
Heyndrickx, A., University of Ghent, Belgium
Gonzales, D. E., Pontifica Universidade Catolica, Rio de Janeiro, Brazil
Ilha Universitaria, Rio de Janeiro, Brazil
Barker, G. O., National Research Council, Ottawa, Canada
Booth, A. H., Dept. National Health & Welfare, Ottawa, Canada
Brearley, N., University of British Columbia, Vancouver, Canada
Canadian Forces Base, Halifax, Canada
Cowper, G., Atomic Energy of Canada Ltd., Chalk River, Canada
Criddle, B. E., DSIS, Ottawa, Canada
Muller, J., Ontario Dept. of Health, Toronto, Canada
Stewart, C. G., Atomic Energy of Canada Ltd., Chalk River, Canada
Toronto, University of, Library, Canada
Weeks, J. L., Whiteshell Nuclear Research Establishment, Pinawa, Manatoba, Canada
Cheng, C. H., National Tsing Hua University, China
Parizek, O., Inst. of Radiation Hygiene, Prague, Czechoslovakia
Faber, M., Finsen Institute, Copenhagen, Denmark
Atomic Energy Research Establishment, England
Bonnell, J. A., Central Electricity Generating Board, London, England
Burch, P. R. J., University of Leeds, England
Burkinshaw, L., University of Leeds, England
Dolphin, G. W., National Radiological Protection Board, Harwell, England
Fowler, J. F., Mt. Vernon Hospital, Northwood, England
Harris, S. J., University of Surrey, England
Loutit, J. F., MRC Radiobiology Unit, Harwell, England

Mayneord, W. V., Tadworth, Surrey, England
Mole, R. H., AERE, Harwell, England
National Radiological Protection Board Library, Harwell, England
Newton, D., AERE, Harwell, England
Owen, M., Churchill Hospital, Headington, England
Pochin, E. E., London University College Hospital Medical School, England
Shaw, D., Keble College, Oxford, England
Smith, H., National Radiological Protection Board, Harwell, England
Spiers, F. W., University of Leeds, England
Vaughan, J., Oxford, England
Vennart, J., MRC, Harwell, England
Institute of Radiation Physics, Helsinki, Finland
Miettinen, J., University of Helsinki, Finland
Coursaget, J., CEA, Saclay, France
Delpla, M., Paris, France
Jammet, H. P., Commissariat a l'Energie Atomique
Gesellschaft fur Strahlenforschung m.b.H., Frankfurt, Germany
Kaul, A., Klinikum Steglitz der F. U., Berlin, Germany
Muth, H., University of Saarlandes, Homburg, Germany
Oberhausen, E., University of Saarlandes, Homburg, Germany
Schales, F., Institut fur Biologia, Frankfurt, Germany
Van Kaick, Gerhard, Inst. fur Nuklearmedizin, Heidelberg, Germany
Vogt, K. J., Kernforschungsanlage, Julich, Germany
Bozoky, L., National Oncological Inst. of Hungary, Budapest, Hungary
Hukkoo, R. K., Bhabha Atomic Research Centre, Bombay, India
Feige, Y., Israel AEC, Yavne, Israel
Benco, A., CCR Euratom, Ispra, Italy
Casnati, E., CNEN, Rome, Italy
Cigna, A. A., CNEN, Rome, Italy
Clemente, G. F., CNEN, Rome, Italy
di Ferrante, E., CCR Euratom, Ispra, Italy
Prodi, V., CNEN Centro di Calcolo, Bologna, Italy
Rimondi, O., CNEN Centro di Calcolo, Bologna, Italy
Selini, G., CSN, Casaccia
Director, Radiation Effects Research Foundation, Hiroshima, Japan
Misono, K., National Institute of Radiological Sciences, Anagawa, Japan
Tanaka, G., National Institute of Radiological Sciences, Anagawa, Japan
Tateno, Y., Dept. Radiology, Chiba University Hospital, Chiba, Japan
Lee, S., Korea Advanced Inst. of Science, Korea
Library, Korea Atomic Energy Res. Inst., Seoul, Korea
van Bekkum, D. W., Radiobiology Institute TNO, Rijswijk, Netherlands
van Putten, L. M., Radiobiological Institute TNO, Rijswijk, Netherlands
Domanski, T., Inst. Occupational Medicine, Lodz, Poland
Jaworawski, Z., Central Lab. Radiological Protection, Warsaw, Poland
Liniecki, J., Inst. Occupational Medicine, Lodz, Poland
Cherry, R. D., University of Cape Town, South Africa
Liden, K., Radiation Physics Department, Lasarette, Lund, Sweden
National Inst. of Radiation Protection, Stockholm, Sweden

Nelson, A. G. A., Research Inst. of National Defence, Sundbyberg, Sweden
Cosandey, M., Service Cantonal de Controle des Irradiations, Geneva
Switzerland
Gunther, A., CERN Scientific Service, Geneva, Switzerland
Hunzinger, W., Federal Office of Public Health, Bern, Switzerland
Poretti, G., Radiuminstitute, Bern, Switzerland
Seelentag, W., WHO, Geneva, Switzerland
Willax, H., Schweiz. Inst. fur Nuklearforschung, Bibliothek, Villigen,
Switzerland
Hazzaa, I. B., Radioisotope Centre for the Arab Countries, Cairo, U.A.R.
Komarov, E., Central Res. Inst. of Roentgenology and Radiology,
Leningrad, U.S.S.R.
Moskalev, Y. I., Ministry of Public Health, Moscow, U.S.S.R.