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ENVIRONMENTAL RESEARCH DIVISION ANNUAL REPORT

Center for Human Radiobiology

July 1983—June 1984

P. F. Gustafson, Acting Division Director

A. F. Stehney, Associate Division Director

April 1985

MASTER

Preceding Report

ANL-83-100 Part II July 1982—June 1983

Foreword

This is the fifteenth Annual Report of the Center for Human Radiobiology; it is only the second since the formation of the Environmental Research Division but, as it happens, the last in this series. Shortly after the period covered by this report, the Center became the Human Radiobiology Section of the Division of Biological and Medical Research. Consequential administrative changes and unrelated reductions in staff have been partly responsible for the delay in publication of this report.

Radium continues to work its insidious effects, and the first paper in the report describes the most recent case of carcinoma of the mastoid air cells, which brings the total number of these rare malignancies to 32 in persons whose radium content has been determined. Of these, 19 occurred in women who were former dial workers. These and other statistics relating to our studies of the late effects of radium are reported in paper 2, which was presented at an international meeting in the Federal Republic of Germany in October 1984. In this connection it is worth mentioning that about 42 percent of the located former dial workers who were first exposed to radium before 1930 are still alive. Some 50 or more of these people had estimated intakes of radium in excess of about 50 μCi, a level that we believe may put them at significant risk for the development of a radium-related malignancy. Also of importance are the 21 former dial workers who have never had their radium contents determined and who are reported to have died with a bone sarcoma or a "head" carcinoma. Paper 4 describes the current status of our exhumation program. A successful disinterment results in the entry for an unmeasured case of malignancy that is currently listed in Table B3 or B4 (Appendix B), being transferred to Table B1 or B2 respectively, if the tumor is confirmed. An exhumation may also provide material that can be sectioned using the technique described in paper 5, for investigation of the distribution of radium (or any other alpha-particle emitter) as described in paper 6. Another in an irregular series of accounts of collaborative work with members of the staff of the University of California at Davis appears as paper 7. If confirmed by others, the experimental results described in paper 8 will have widespread ramifications for the interpretation of bone cancer incidence data.

Papers 9-11 refer to our investigations of the health effects of thorium in former refinery workers. The first of these was presented at the same meeting as paper 2, and it demonstrates well the dosimetric problems that result from the radiological properties of the thorium decay series. Paper 10 presents some intriguing correlations that may have physical, rather than physiological, explanations. Paper 12, also presented at the meeting in Germany, describes a joint effort with a colleague at the University of Utah to determine the state of equilibrium of daughter products of ^{224}Ra in bone surface deposits. Such information is relevant to our work because of the ingestion of ^{224}Ra by dial painters exposed to ^{228}Ra. Papers 13 and 14 deal with plutonium in mammals; previous conclusions concerning metabolism in the baboon were found to be invalid because of contamination of urine by unabsorbed plutonium in the feces. The final contribution deals with the stability, efficiency, and precision of our radon counting systems.

The report concludes with the usual appendices, list of publications and presentations, and organizational listing. Appendix A contains data on the exposure of 2400 persons whose radium content has been determined, while the tables in Appendix B list the bone sarcomas and carcinomas of the paranasal sinuses and mastoid air cells.

Although it did not occur within the period covered by this report, the retirement of Dr. Andrew F. Stehney at the end of September 1984 was an event that we record with regret. Dr. Stehney had been responsible for the day-to-day operation of the Center from its inception in 1969 until his appointment as Acting Director of the Radiological and Environmental Research Division, and again on the retirement of Dr. Robert E. Rowland. We are fortunate that Dr. Stehney's continued association with the Center on a Special Term Appointment permits us to draw on his knowledge and experience in the field of human radiobiology.

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Abstract

Epidemiological studies of the late effects of internal radium in man, and mechanistic investigations of those effects, have continued. The current status of the study is summarized. An experimental technique for preparing thin sections of bone and the application of that technique in studying the comparative distribution of radium and plutonium are described. Radiological dental changes due to radium in man and dog are compared. Survival of human fibroblasts irradiated with alpha particles *in vitro* was found to be higher when the average LET was higher. In the study of the late effects of thorium in man, the relative activities of the daughter products in the lung have been determined spectrometrically *in vivo*. The exhalation of thoron in these persons has been investigated in relation to lung burden of thorium and to personal factors such as smoking, age, and weight. The administration of two isotopes to large mammals has been used to demonstrate that the metabolism of plutonium is independent of route of entry and to determine the gastrointestinal absorption of plutonium. The effect of thermoluminescence on a scintillation radon counting system has been investigated quantitatively. Data on the exposure of 88 persons to radium were added to the data base, bringing the total to 2400 radium cases under study by the Center for Human Radiobiology.

A RECENT CASE OF RADIUM-INDUCED MALIGNANCY

Evelyn E. Adams

One new case of malignant disease attributed to radium in a patient with a measured body burden has been reported since 1981; this case, with a squamous cell carcinoma of the left mastoid, is summarized here.

Previous reports[1,2,3] have listed ten cases of head carcinoma and four cases of bone sarcoma that occurred between 1969 and 1981 in persons under surveillance by the Center for Human Radiobiology. This report describes one case of malignancy found since 1981 that is presumed to be radium-related. The case involves a mastoid carcinoma.

Case 03-433

Born in 1904, this woman was employed as a dial painter in an Illinois plant for 27 months (1924-26). She pointed the brush in her mouth. She married and had three pregnancies, two of which ended in miscarriage. In 1931 in Germany, tuberculosis of the spine was suspected, but this diagnosis was never confirmed. When measured at Argonne in 1957 her radium body burden was reported to be 0.420 μCi and X-ray changes thought to be due to radium were noted in most of her bones. The mastoids were recorded as densely sclerotic. In July 1983, she was hospitalized for complaints of left ear drainage for two months and left seventh nerve paralysis for ten days. Exploratory surgery of the left mastoid revealed a squamous cell carcinoma, which was removed. Postoperatively the patient was given local radiotherapy and she is still living. The estimated average absorbed dose to her skeleton from the ingested radium is 4228 rads.

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3. E. E. Adams, Recent cases of radium-induced malignancy, Environmental Research Division Annual Report, July 1982-June 1983, ANL-83-100, Part II, pp. 1-3.

CURRENT (1984) STATUS OF THE STUDY OF ^{226}Ra AND ^{228}Ra IN HUMANS AT THE CENTER FOR HUMAN RADIOBIOLOGY*

J. Rundo, A. T. Keane, H. F. Lucas, R. A. Schlenker, J. H. Stebbings and A. F. Stehney

The Center for Human Radiobiology has identified 5784 persons by name and type of exposure to ^{226}Ra and ^{228}Ra. Included are 4863 dial painters (mostly women) and non-laboratory employees of the radium dial industry, 410 laboratory workers, 399 persons who received radium for supposed therapeutic effects, and 112 in other categories. Body contents of radium have been measured in 1916 of the dial workers and about one-half of the subjects in the other groups. Bone sarcomas, carcinomas of the paranasal sinuses and mastoids, and deterioration of skeletal tissue are still the only effects unequivocally attributable to internal radium. Excess leukemias have not been observed and other malignancies, if in excess, appear more likely to be related to external gamma radiation or radon than to internal radium. Positive correlations with radium burdens have been found for the incidence of benign exostoses among subjects exposed to radium before age 18 and for shortened latency of ocular cataracts.

Introduction

The year 1984 is both the 60th anniversary of the first report[1] of deleterious effects ("radium jaw") of internally deposited isotopes of radium and the 15th anniversary of the formation of the Center for Human Radiobiology (CHR) at Argonne National Laboratory (ANL). Ten years ago at a meeting held in Alta, Utah, R. E. Rowland presented a paper with a title similar to ours.[2] The present report is, in effect, a revision of Rowland's paper; it demonstrates the progress made in 15 years and suggests areas where work remains to be done.

The Population

It would be inappropriate to review here the early studies of the health effects of internal radium even if space permitted it; we merely draw attention to some major reports, such as those by Martland et al.,[3] Aub et

*Presented at the Symposium on the Radiobiology of Radium and Thorotrast, Neuherberg, Federal Republic of Germany, October 29-31, 1984. To be published in the proceedings.

al.,[4] Evans et al.,[5,6] Miller et al.,[7] and that of the New Jersey Radium Research Project.[8] The last four contain details of the numbers of persons, with their types of exposures, who constituted the population under study at the time of the formation of the CHR. Data collected from these reports are shown in Table 1. It can be seen that the number of persons for whom radium burdens have been measured has more than doubled since the formation of the

TABLE 1. Numbers of persons with measured radium contents, by class of exposure, September 1969 and June 1984.

Source of Data	Dial workers	Medical cases	Chemists and other exposures	Totals
MIT[5,6]	367	69	168	604
ANL/ACRH[7]	277	71	16	364
NJRRP[8]	113	1	47	161
Totals	757	141	231	1129[a]
CHR 1969	734	139	226	1099
CHR 1984	1916	166	292[b]	2374

[a]Some cases were included in reports from more than one laboratory.
[b]239 were chemists or other laboratory or clinical personnel.

TABLE 2. Radium cases, by class of exposure, June 1984, for comparison with the situation in April 1974.[2]

Radium Cases	Dial work	Laboratory	Medical	Other	Totals
Located, measured					
Living	1410	99	18	39	1566
Dead	497	137	144	13	791
Lost	9	3	4	1	17
Located, not measured					
Living	1269	17	44	3	1333
Dead	856	78	88	17	1039
Lost	19	2	7	1	29
Not located	803	74	94	38	1009
Totals	4863	410	399	112	5784

CHR. All the subjects entered into Table 1 have had their radium contents determined, either in vivo or postmortem, and the health status of each person measured in vivo has been evaluated. For those measured postmortem and those who died after measurement, death certificates and medical records have been obtained.

Of almost equal interest to us is the mortality follow-up of the unmeasured subjects. Table 2 shows the current status of almost 6000 persons potentially exposed to ^{226}Ra and/or ^{228}Ra whose names we now have. These data may be compared directly with those in Table 1 of the 1974 review by Rowland et al.[2] That review defined "studied" cases only as those with measured radium contents, even though medical records and/or death certificates had been obtained for many of the persons whose body burdens of radium had not been determined; in this paper we use the terms "measured" and "unmeasured" to avoid the implication that nothing is known about the health status of the latter. Our total of cases identified by name and type of exposure is 1981 more than that reported in the 1974 review. Of those reported in 1974, 46 persons have been lost from the follow-up. To keep this number to a minimum continual contact is necessary.

Radium in the population

Our methods for measuring radium in vivo have been described in detail.[9] The body content of radium decreases with time, so it is not a suitable parameter for use in comparing subjects who acquired their radium 30-60 years prior to measurement. We therefore apply the Norris retention function,[10]

$$R_t = 0.54R_0t^{-0.52}$$

where R_t is the retention t days after intake to the blood of R_0 units (e.g., μCi) of radium. From the experimentally determined value of R_t we calculate R_0. Correction for radioactive decay of ^{226}Ra is small (2.2% for a 50-year period), but the correction for ^{228}Ra (half-life 5.75 years) is substantial, amounting to a factor of more than 400 for a 50-year period. Because of radioactive decay, in-vivo measurements of ^{228}Ra are rarely possible in subjects examined in recent years; instead, we estimate the intakes of ^{228}Ra from measurements of ^{226}Ra and knowledge of the ratios of ^{228}Ra to ^{226}Ra in persons with similar exposure histories or in radium materials to which the subjects were exposed. Because the power of ^{228}Ra to induce bone cancer is estimated to be 2.5 times that of ^{226}Ra on an activity basis,[11] we calculate what may be called an "effective" systemic radium intake as the sum of the ^{226}Ra intake and 2.5 times the ^{228}Ra intake, both expressed in μCi. For various other effects, estimates of the relative effectiveness of ^{228}Ra have ranged from zero to six.[11-15]

Cohorts of former dial workers, although still incomplete, are far more complete than any of the other major exposure groups (medical cases, chemists, etc). We therefore concentrate on them in what follows. Figure 1 shows the intake of radium to the blood, calculated as described above, as a function of year of first exposure for the former dial workers whose body contents of

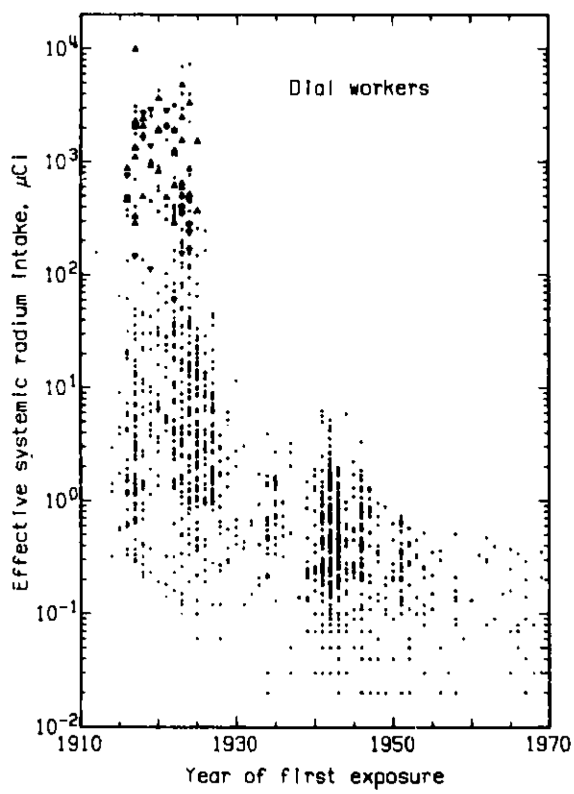

FIG. 1.--Effective systemic radium intake, defined as the sum of the ^{226}Ra intake, and 2.5 times the ^{228}Ra intake, both expressed in μCi (see text), as a function of year of first exposure for 1916 dial workers. Not plotted are 9 cases with measurable radium first exposed after 1970 and a number of cases with intakes of less than 0.01 μCi. Points plotted as upright triangles are for persons who developed bone sarcomas, while inverted triangles represent persons with "head" carcinomas.

radium have been measured. The 60 subjects who developed radium-related malignancies (see below) are identified by a distinctive symbol. Three main points are apparent. First, radium intakes dropped dramatically for persons year of first exposure was after 1925, when recommendations were made against the pointing of the radium-laden brush in the mouth.[16] Second, no dial worker with an intake of less than about 60 μCi developed a radium-related malignancy. Third, there are two distinct time-cohorts, before and after the

1930s, with the radium intakes of the later group still significant, but much lower than those of the early group.

Effects of Radium

The "Classical" Malignancies. At the time of writing, we know of 62 bone cancers (osteo- and fibrosarcomas) and 32 carcinomas of the paranasal sinuses or mastoids ("head" carcinomas) in 89 persons in the measured population, and 23 bone cancers and 5 "head" carcinomas in the unmeasured cases. These data and the sizes of the populations are given in Tables 3 and 4 in the same format as Tables 5 and 6 in the 1974 paper by Rowland et al.[2] In the studied population, since 1974 we have found eight more cases of bone cancer and six more "head" carcinomas. These differences can be attributed to new cases (three and five respectively), to exhumations of the remains of four previously unmeasured persons who had died with bone cancer between 1929 and 1946, to the revision of a 1957 diagnosis as mastoid carcinoma, and to acquisition of a 1959 death certificate showing bone cancer diagnosed two years earlier as a contributory cause of death. Despite the transfer of four cases to the measured category, the number of unmeasured bone cancer cases has only decreased by one, because four cases have been added to the list as a result of the review of medical records, while one exhumed body showed no evidence of bone cancer. The additional cases of bone cancer among the measured persons have no significant effect on the dose-response relationships

TABLE 3. Radium-induced malignancies in the measured population.

Measured cases	Persons	Bone tumors	Sinus or mastoid carcinomas
Total population			
Living	1566	1	1
Dead	791	61	31
Totals	2357	62[a]	32[a]
Dial workers			
Living	1410	1	1
Dead	497	43	18
Total	1907	44[b]	19[b]

[a]Five persons developed malignancies of both kinds.
[b]Three dial workers developed malignancies of both kinds.

reported in 1978[11] and 1983.[17] The most recent case occurred in 1981 (see Figure 2). A final value for the effective radium intake in this case awaits the completion of analyses for ^{228}Ra in bone samples obtained postmortem in 1983.

TABLE 4. Probable or confirmed malignancies in the unmeasured radium cases.

Unmeasured cases	Persons	Malignant bone tumors	Sinus or mastoid carcinomas
Total population			
Located			
Living	1333	0	0
Dead	1039	23	5
Not located	1009	-	-
Totals	3381	23	5
Dial workers			
Located			
Living	1269	0	0
Dead	856	20	5
Not located	803	-	-
Totals	2928	20	5

The time distribution of the appearance of the two types of tumor is shown in Figure 2. The points plotted as circles and crosses are the same data as plotted by Rowland et al. in 1974, with some corrections and changes due to revision of records and other factors. The additions since then are

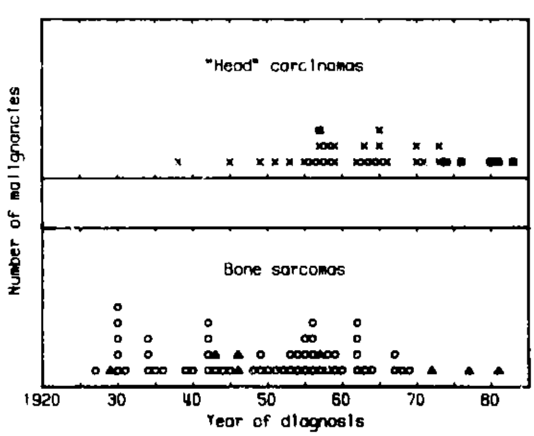

FIG. 2.--The year of diagnosis for each of the 62 malignant bone tumors and 32 "head" carcinomas in the total measured population. Compare with Fig. 5 in Rowland et al.[2] Solid symbols are for malignancies that have arisen or been discovered (see text) since the 1974 reivew.

shown as distinctive solid symbols. In 1974, Rowland wrote, "Noteworthy is the observation that no bone tumors have been diagnosed since 1969. Whether this 4-yr respite is a statistical fluke or an indication that the induction of these tumors is at an end remains to be seen."[2] We now know of three bone tumors that have appeared since 1969, and "head" carcinomas have continued to appear at a greater rate than bone cancers. We still can not write "Finis" to this sad episode in the experience of the radium dial workers.

Other Cancers. A study of the relationships of radium exposure to mortality from cancers of the stomach, pancreas, colon, rectum, liver, breast, lung, cervix, and corpus uteri, in 1285 female dial workers exposed before 1930, has been published recently.[15] In that study the observed mortality was compared with that expected from rates for U.S. white females, both with and without adjustment for local mortality rates. Mortality from cancers of the liver, pancreas, cervix, and corpus uteri was clearly unrelated to radium exposure. Because the gastrointestinal tract was exposed to radiation from the ingested radium, there is special interest in cancers in this region. However, cancers of the stomach, colon, and rectum appeared to be only indirectly, if at all, associated with exposure to radium. Lung cancer requires further investigation, and the possibility that radon may have played a role must be seriously considered. In an earlier publication,[12] a clear relationship was reported between radium intake and breast cancer in the early cohort. Further study[7,18] uncovered several observations that were inconsistent with a causal interpretation of that relationship. The three workplaces that contributed the great majority of observed and expected breast cancers showed a highly statistically significant heterogeneity. Thus, for one plant, the standardized mortality ratio (SMR) for breast cancer in women, both measured and unmeasured, and first exposed before 1930 was 0.15, while for the other two plants the SMR was about 2.0. Also, the SMR for breast cancer in the 1930-1949 cohort at this plant was 1.95.

Cuzick's conclusion[19] that internal alpha-particle emitters confer an elevated risk of multiple myeloma compared with external radiation, rested largely on the observation of six cases (2.15 expected) in the dial workers. It now appears[15,18] that duration of employment, a surrogate for external gamma radiation, rather than internal radium, is the more likely explanation for the association between dial work and multiple myeloma.

No excess incidence of leukemia was observed in a recent detailed analysis[18] confirming the initial report of Spiers et al.[20] Nine cases (seven fatal) were observed among the female dial workers, and six among radium-exposed males. Two cases of erythrocytic leukemia occurred among the males, and none among the females. A similar disproportionation between the sexes for this rare form of myeloproliferative disease can be observed when studies of the late effects of Thorotrast[21,22] in man are reviewed. Chronically irradiated beagles at ANL also show the same effect.[23]

In conclusion, malignancies attributable to radium are still dominated by a huge preponderance of the "classical" tumors, i.e. bone sarcoma and carcinoma of a paranasal sinus or mastoid. However, the detailed studies that have been undertaken in recent years are uncovering some findings of considerable interest, although the only finding of outstanding importance relates to the relative lack of effects on hematopoietic tissues.

Non-stochastic Effects. Rarefaction of areas of bone, termed "radiation osteitis" by Martland,[12] was described by Aub et al.[4] as "the fundamental lesion observed as a late effect of internally-deposited radium." A scoring method developed by Finkel et al.[25] for quantifying radiographically observed changes,[8] was modified to yield a uniform system that was used in an essentially unchanged fashion by the Massachusetts Institute of Technology (MIT), ANL (pre-CHR), and CHR radiologists. Recently Keane et al.[14] analyzed the x-ray scores in relation to systemic intake of radium; they observed a dose-response relationship between the average rate of accumulation of score (score divided by time from first exposure to radiography) and the systemic intake of radium. A very important finding was that on an equal activity basis, ^{226}Ra and ^{228}Ra produced essentially identical effects.

Other Effects. Effects have been attributed to ^{224}Ra,[26,27] such as ocular cataract and benign exostoses, that have not been a prominent feature in our series. Adams et al.[13] reviewed ocular cataract incidence in 813 measured female radium dial workers first exposed before 1930, and noted that the lifetime incidence appeared not to be increased in subjects with high systemic intakes (>50 μCi) of radium (24 cataracts in 140 subjects versus 95 in 673 subjects with lower intakes). However, they noted a highly significant difference during the first 40 years after radium exposure: eight cataracts in 5412 person-years of follow-up in the high-dose group versus only seven in 35,975 person-years in the low-dose group. This work has not been pursued.

In the discussion of the paper by Rowland et al.,[2] Spiess reported that exostoses occurred only in persons who received ^{224}Ra as juveniles. A very preliminary search of our records yielded similar results. For 482 females and 64 males first exposed to radium at age 17 or younger and whose radium content has been determined, reports were found of exostosis, osteoma, or osteochondroma in 22 of the females and 3 of the males, and there is a strong suggestion of a positive dose-response relationship. However, the numbers are small, and because the condition is benign we have not assigned its further study a high priority.

Exhumations

Figure 3, taken from Rowland et al.,[17] shows the dose-squared exponential dose-response function (lower bound of the shaded area) that best fitted the then-existing data on bone cancers in female dial workers exposed before 1950, and the linear-quadratic-exponential function (upper bound of the shaded area) that still fitted acceptably ($p=0.05$). The circular points represent zero values observed in intake intervals below 100 μCi, whereas the triangles show where each point would be if one malignancy occurred in that interval. Since there are 23 cases of bone cancer in unmeasured persons (20 in dial workers, Table 4), there remains the possibility of one or more cases at radium intakes of less than 100 μCi and thus within the range plotted in Figure 3.

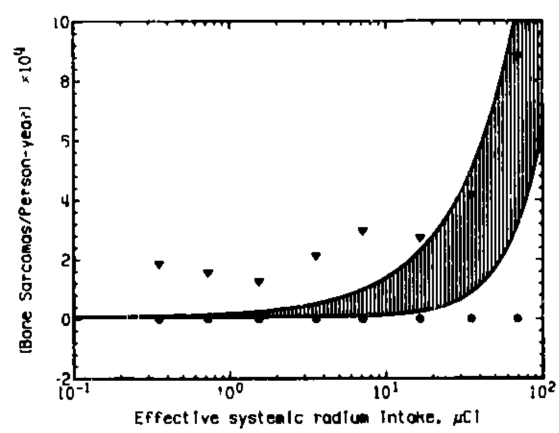

FIG. 3.--Bone sarcomas per person-year at risk versus systemic intake on a logarithmic scale for the dose region where these tumors have not been observed. See text for explanation.

Exhumations of unmeasured bone cancer cases are needed to test this possibility and would provide data to improve confidence in extrapolation in this low-dose region.

An active program in which 69 persons were exhumed under the aegis of the CHR was interrupted in late 1979 because of a reduction in support. The program was reactivated in 1983, with efforts concentrated on the unmeasured persons with bone cancer. The current status of this program is summarized in Table 5. The exhumation of one of the cases in June 1984 leaves 23 cases (20 former dial workers), as shown in Table 4. The systemic intake of the recently exhumed case has been estimated at about 860 μCi, in line with the intakes that led to bone cancers in the dial workers plotted in Figure 1. Although the exhumations of three other cases have been approved by next-of-kin, we are still some way from actually having the exhumations carried out. For those cases where next-of-kin have not responded or have not been located, it is conceivable that we might be able to carry out court-authorized exhumations.

TABLE 5. Status of program reactivated in 1983 for exhumation of 21 unmeasured former radium dial painters with probable or confirmed bone sarcomas.

Status	Number of cases	Exposed	Died
Exhumed	1	1924	1946
Exhumation approved by next-of-kin	3	1920-24	1940-58
Awaiting permission by next-of-kin	4	1917-23	1931-62
No response from next-of-kin	5	1917-24	1924-47
No relatives located	3	1917-23	1931-39
Exhumation refused by next-of-kin	5	1917-24	1930-56

Concluding Remarks

Progress in this study since 1974 has been substantial. Almost 2000 persons have been added to the total, and of these, we have been able to measure the radium contents of nearly 800. The number of unlocated persons has remained unchanged despite the 52% increase in the known population.

Bone sarcomas and carcinomas of the paranasal sinuses or mastoid air cells are still appearing, the latter at a rate that indicates that there are more to come. We can be less dogmatic about eventual future bone sarcomas. The existence of other radium-related cancers is still equivocal, although we can say that major carcinogenic effects on the hematopoietic system have not occurred. Non-stochastic effects on the skeleton ("radiation osteitis") have been quantified and a dose-response relation determined, but the relationship of this damage to eventual sarcomagenesis is obscure.

ACKNOWLEDGMENTS

The work summarized in this paper has come about as the result of the efforts of many persons. We thank especially all our colleagues and former colleagues in the CHR, and M. H. Chalfen and M. M. Shanahan formerly of the MIT Radioactivity Center. We gratefully acknowledge the scientific and administrative leadership of R. E. Rowland until 1981.

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MORTALITY FROM CANCERS OF MAJOR SITES IN FEMALE RADIUM DIAL WORKERS

J. H. Stebbings, H. F. Lucas and A. F. Stehney

The female radium dial workers have now experienced significant mortality from cancers other than the bone sarcomas and head carcinomas long known to be radium induced. The relationships of radium exposure to mortality from cancers of the stomach, pancreas, colon, rectum, liver, lung, breast, cervix, and corpus uteri, and from leukemia were studied in 1285 pre-1930 dial workers. Mortality was compared with that expected from rates for US white females, with and without adjustment for local area mortality rates, and with mortality in dial wokers exposed from 1930 to 1949. For the 693 cases whose body content of radium has been measured since 1955, dose-response relationships of cancer to systemic intake of radium and duration of employment were examined. Liver, pancreatic, cervical, and uterine cancers were clearly unrelated to radium exposure. Other cancers of the digestive tract appeared to be indirectly, if at all, associated with work in radium facilities. Lung cancer requires further investigation; inhalation exposures of the dial workers are reviewed. Analyses of the breast cancer data uncovered several observations inconsistent with the previously suggested causal association with radium exposure. Multiple myeloma was also reviewed. A three-fold excess risk of death due to multiple myeloma has occurred, but is more closely correlated with duration of employment (a surrogate for external gamma radiation) than with radium intake.

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*Abstract of a paper published in the Am. J. Indust. Med. 5, 435-459 (1984).

CURRENT CHR EXHUMATION PROGRAM

A. F. Stehney and G. J. Hamilton

The CHR exhumation program was reactivated in 1983 with efforts concentrated on the 24 unmeasured radium cases with probable or confirmed bone sarcomas. By the end of June 1984, one of these cases had been exhumed, approval of all next-of-kin had been obtained for 4 cases, and refusals had been received for 6 cases. Relatives of 10 other cases had been located but had not responded to our attempts to contact them (6 cases) or had not yet reached a decision (4 cases).

After its formation in 1969, the Center for Human Radiobiology (CHR) continued an exhumation program that originated in the Radioactivity Center of the Massachusetts Institute of Techology (MIT). The primary purpose was to obtain radioactivity measurements and skeletal x rays of radium cases who had died prior to the start of cohort studies in the 1950s. MIT exhumed the remains of 66 cases during the period of 1958-1969, and CHR exhumed 56 cases during the following 10 years. These cases have provided valuable data on the amounts of skeletal distribution of radium, ratios of ^{228}Ra to ^{226}Ra, and the early time development of skeletal changes due to radium. In one case a suspected bone sarcoma was ruled out by inspection of the skeletal remains. However, the total number exhumed falls far short of the estimate of 500 cases needed to complete the study of early dial painters and iatrogenic cases.[1] The chief difficulty has been in obtaining permission to exhume from the surviving next-of-kin, who number 5 or more for some cases.

This program has been largely inactive since 1980 because of personnel reductions and greater emphasis on post-1930 cohorts of dial workers. However, it was reactivated in 1983, with efforts concentrated on the unmeasured persons with probable or confirmed bone sarcomas. This group, listed in Table B-3, Appendix B of this report, comprises 21 female radium dial painters, 2 iatrogenic cases, and 1 radium chemist. After review of past records, it was decided to attempt contacts with the surviving next-of-kin of all but two of these cases, including 13 cases for which one or more relatives had previously refused permission to disinter. The exceptions were an iatrogenic case for which permission was refused in 1980 and one case (chemist) that will require court approval in addition to permission already given by relatives.

Search for the closest surviving relatives of 22 cases began in November 1983, and by the end of June 1984, current locations of the relatives of 19 cases had been ascertained. During this period, one case was exhumed, permission of all closest relatives were obtained for 3 cases and refusals were received for 6 cases. A case-by-case summary of the current status of this program is given in Table 1.

TABLE 1. Status of program for exhumation of 24 unmeasured cases with probable or confirmed bone sarcomas (June 1984).

Response of next-of-kin	Case numbers
Approved	00-031, 03-680[a], 03-800, 03-848, 09-087
Undecided	00-011, 01-088, 03-658[b], 05-987
No response	00-013[c], 00-030, 00-035, 01-107, 01-108, 03-660
No kin located	01-117, 01-695, 05-534
Refused	01-387, 01-465, 03-661, 03-665, 03-759, 03-806

[a]Exhumed, June 1984

[b]Approved, August 1984

[c]Refused, July 1984

Reference

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A PRODUCTION TECHNIQUE FOR THIN UNDECALCIFIED BONE SECTIONS SUITABLE FOR AUTORADIOGRAPHY

J. E. Farnham and R. A. Schlenker

The production of thin bone sections using power-driven grinding equipment is described.

Introduction

The determination of alpha particle doses to the cells at risk in bone requires measurement of the spatial distribution of radioactivity within bone sections. This is accomplished by bringing autoradiographs into registration with the sections to which they were exposed and collecting data from the autoradiographs at sites of interest identified in the sections. A typical measurement would involve determination of optical density or track number on the autoradiograph at bone surfaces in the section. The latter occur at junctions between the mineralized matrix and the plastic embedding medium. In order for the junctions to be accurately located by microscopic examination, the sections should be thin. For work with cortical bone, 100-μm sections are usually adequate. With trabecular bone, however, the sections must be thinner because the natural curvature of the trabecular surfaces causes the mineral-plastic junction to change location as one focuses down through the section with the microscope. This makes it difficult to tell exactly where the junction lies. The problem is worse when microradiographs are used as a substitute for the sections because the trabecular surfaces appear fuzzy unless the sections are very thin.

There are two ways of producing sections thinner than 100 μm, microtomy and grinding. Sections produced by the former method are usually torn or distorted. Therefore, we have concentrated on the latter method.

The traditional approach is to begin with a section that is nominally 100 μm thick and to grind it by hand between glass microscope slides, whose surfaces have been abraded, until the section is 50 to 70 μm thick. Most sections are damaged by the grinding process and rendered useless. Those that survive are usually still too thick for good results in autoradiography. These problems have prompted us to adapt automatic grinding equipment, normally used in materials science, to the production of thin sections. With such equipment, sections can be readily ground to thicknesses between 30 and 40 μm in a rapid and controlled fashion. The yield of usable sections is nearly 100%.

Equipment

The equipment used is a Logitech Model LP30 Production Lapping and Optical Polishing Machine (Logitech Ltd., Glasgow, Scotland), which contains a motor-driven rotating cast-iron lapping plate for grinding and a Logitech Precision Lapping Jig with vacuum chuck (Model PLJ-2) that allows samples mounted on glass slides to be uniformly ground on the cast-iron plate to a specified thickness.

Bone

All bone used so far in our developmental work has been dry or frozen prior to embedding. There appears to be no reason why fresh bone, stripped of extraneous tissues and properly fixed, could not also be used. Our samples were obtained from the CHR collection of specimens from radium cases.

Embedding

Embedding has been in methyl methacrylate using the following procedure:

1. Defat specimen by prolonged exposure to a 50:50 mixture of methanol and ether. Place specimen in a glass jar and cover it with catalyzed, inhibitor-free, liquid monomer. Cycle between atmospheric pressure and vacuum until all air has been removed from the specimen. Change monomer several times during the period of cycling.
2. Without removing monomer, cover the specimen with degassed, partially polymerized methyl methacrylate. This material is prepared by gently heating the monomer until it reaches the consistency of heavy syrup. Degassing is done with an aspirator.
3. Polymerization of the methyl methacrylate will proceed spontaneously at room temperature or in a pressure vessel or oven.

When specimens are more than one inch thick, a variant produces the best results:

1. Same as 1 above.
2. Add partially polymerized monomer to a depth of about one-half inch.

3. Allow polymerization to proceed at room temperature, but not to completion.
4. Repeat steps 2 and 3 until the specimen is covered, and then allow polymerization to proceed to completion. In this way, the generation of excessive heat of polymerization, which can ruin the embedding process, is avoided.

After embedding, the glass jars are broken away, and the plastic is trimmed to within a quarter inch of the specimen on all sides using a band saw and belt sander.

Grinding

From this point, the preparation of thin sections proceeds in three steps. First, the face of the specimen that was in contact with the bottom of the embedding jar is ground flat. Second, this face is attached to a glass slide and the opposite end of the specimen is sawn off to leave a section no more than about 0.2 mm thick. Third, the section is ground to final dimensions.

In step one, the embedded samples are placed face down against the cast-iron lapping plate of the LP-30 and ground with an abrasive slurry consisting of aluminum oxide powder, with a nominal particle size of 9 μm, suspended in water (Chemical-Ways Corporation, Lake Bluff, Illinois). The slurry is fed onto the lapping plate at a constant drip rate from a large reservoir, and the samples are confined within a retaining ring with an inside diameter of about 4 inches and pressed down with a heavy weight.

In step two, the ground surface is attached to a 1-inch by 3-inch glass or plastic slide by placing three or four drops of epoxy resin on the slide and allowing the specimen to settle into the resin with the aid of gentle finger pressure. The slide and block are then placed in a spring loaded jig (Logitech Model BJ10), which clamps the slide and block until curing is complete. The slides are prepared for use by grinding both sides on the cast-iron plate until the slide surfaces are perfectly flat and parallel to one another. This is an essential step that guarantees that the flat, ground surface of the specimen will butt against a flat surface on the slide.

The unattached end of the specimen is cut off using an annular rotary saw (Metals Research Microslice 4 Precision Cutting Saw, Cambridge Instrument Company Inc., Monsey, New York), with the slide held in position by a vacuum chuck. The specimen can be reground and remounted as described previously.

In step 3, the slide is ground with the Logitech Precision Lapping Jig, which consists of a movable vacuum chuck held within a hollow steel cylinder. By varying the distance which the cylinder end (also called the stop ring) extends beyond the chuck face, one can vary the final thickness of mounted sections held by the chuck. The usual procedure is to place four slides on the chuck face (maximum capacity), draw vacuum to hold them in place, set the cylinder end so that the section surfaces extend beyond it, and then grind. Grinding continues until the cylinder end meets the slurry-covered cast-iron plate.

Grinding is usually done in stages until the final section thickness is attained. In the first stage, the rough surface produced by the annular saw cut is removed. Subsequent stages are designed to remove 20 μm at a time from the section. The slurry undercuts the cylinder end by 15 μm, i.e., after grinding, the section surface lies 15 μm from the plane of the cylinder end. Thus, to remove 20 μm from the section, the lapping jig is adjusted so that the section surface extends 5 μm beyond the cylinder end before grinding. Coarser abrasives produce a greater undercut, e.g., a slurry of 15-μm aluminum oxide powder would produce a 30-μm undercut. With the 9-μm abrasive, about 1 minute is required for each micrometer removed. Thus, about 20 minutes are required to remove 20 μm.

Between grindings, the sections are gently cleaned with water and examined. The undercut is checked with dial gauges. The section thickness is determined by subtraction of the slide thickness plus undercut from the distance between the chuck face and cylinder end. Just before the next grinding step, the chuck is moved toward the cylinder end by 20 μm.

Sections less than 30 μm thick cannot be satisfactorily ground using 9-μm abrasives. However, thinner sections can be obtained using finer abrasives. This requires a separate lapping plate or very thorough cleaning of the 9-μm plate to remove all other abrasive material.

Staining

When 30-μm-thick ground bone sections are viewed with transmitted light, the mineral bone is somewhat difficult to see. It can be brought out with biological stains. To obtain high contrast with the embedding plastic, we flood the sections with a 5% aqueous solution of silver nitrate and place them in direct sunlight for about 60 minutes or under an ultraviolet lamp for 15 minutes. After light exposure, the sections are washed by repeated dipping in distilled water to remove excess stain and air dried. The bone is then quite visible.

Bone Surfaces

With 30-μm sections, the interface between the bone mineral and embedding plastic is much sharper than with 100-μm sections. Lack of clarity in the location of the bone surface occurs only rarely in comparison with 100-μm-thick sections.

Mass Production

Compared with hand grinding, the machine grinding process described here is better controlled, more rapid, and has a much higher yield. In order to determine radioactivity concentrations at bone surfaces throughout the skeleton, autoradiographs are needed. It appears that thin-ground sections could be produced at the rate of several hundred to about a thousand per year with the equipment now on hand.

Future Work

This work is part of a project to provide data for bone cell dosimetry in radium cases. Future efforts will focus on the production of autoradiographs and the search for a method of rapid data collection to complement our mass production capabilities.

THE DISTRIBUTION OF RADIUM AND PLUTONIUM IN HUMAN BONE*

Robert A. Schlenker

This review covers studies of the microdistribution of radium and plutonium in human bone, conducted at Argonne with emphasis on the alpha-spectrometric method of measurement. Alpha spectrometry offers high spatial resolution and is well suited to the measurement of radionuclide concentrations near bone surfaces. With these techniques surface deposit thicknesses have been measured to be about 1 μm thick for isotopes of lead, radium and the actinides, and volume deposits of ^{226}Ra have been found to be quite nonuniform near bone surfaces, leading to endosteal tissue dose rates that are higher than expected under the assumption of uniform volume concentration normally used in radiation protection calculations. With autoradiography, the bony septa of the mastoid air cell system have been found to be depleted in radium relative to the bone tissue surrounding them; this is expected to have a significant influence on the dosimetry of the mastoid epithelia. A combination of autoradiographic and morphometric measurements indicates that specific activities in the axial skeleton are higher than in the appendicular skeleton, primarily because the former has higher bone surface-to-volume ratios and higher bone surface concentrations of plutonium.

Introduction

The dosimetry of radionuclides in bone provides information essential to the interpretation of radiation effects data. The relative biological effectiveness of different radiations is expressed as a ratio of absorbed doses, and doses or dose equivalents are the intermediaries through which the risk from one radionuclide is estimated on the basis of the risk data for another radionuclide. Because a wealth of information on the skeletal effects of radiation in humans has been accumulated in the study of radium poisoning, bone dosimetry has played an important role in the development of radiation protection standards.

Historically, energy deposition in the whole skeleton was the quantity used in radiation protection calculations for internal emitters, but within the last few years, the International Commission on Radiological Protection (ICRP) has shifted attention to bone-surface tissue dose.[1] For the alpha

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emitters, the experimental study of dosimetry is difficult because it must be carried out on a microscopic scale; therefore, methodology is an important aspect of the work. Traditionally, the necessary data have been collected from autoradiographs, but alpha spectrometry is being developed as a research tool in this field. Aspects of current and recent work conducted at Argonne National Laboratory on the distribution of radium and plutonium near the surfaces of human bone and applications of the data are summarized in this paper. Topics covered include methods, surface deposit thickness, radium distribution near the endosteal surface, the use of alpha spectrometry in conjunction with autoradiography, radium distribution in the mastoid, and factors affecting the specific activity of plutonium. Emphasis is placed on the alpha spectrometry technique because of its usefulness and its recent application to problems of local dosimetry.

Methods

Alpha Spectrometry. Because the energy loss of alpha particles in matter is well understood, it is possible to extract information on the spatial distribution of an alpha emitter within the effective sample volume* from the alpha energy spectrum, dn/dE, of a thick embedded or unembedded bone sample. By the chain rule of differential calculus, $dn/dx = (dn/dE)(dE/dx)$, where dn/dE is the number of alpha particles reaching the detector with energies between E and E + dE, dn/dx is the number of alpha particles that travel distances in bone between x and x + dx before escaping into the vacuum between the sample and the detector,[2] and dE/dx is the stopping power. The distance spectrum, dn/dx, is closely related to the spatial distribution of the alpha emitter. For plane samples measured with a sample-to-detector distance that is much greater than the largest sample dimension, dn/dx is directly proportional to the average concentration of emitter as a function of depth beneath the surface. Because the energy resolution of surface barrier detectors is so great, typically 40 to 50 keV for alphas of 3 to 9 MeV, the resolution of the distance spectrum is also high, less than 1 μm under optimum conditions.[2]

*The effective sample volume is the surface layer of bone to a depth of one alpha particle range.

Stripping techniques can be used to resolve energy spectra of radionuclide mixtures into separate components and to establish the relative abundances of the nuclides. It is also possible to obtain a quantitative calibration that permits the estimation of radionuclide concentration.

Figure 1 illustrates the duality between energy and distance spectra. An energy spectrum with the shape of a linear ramp is shown to the left; beside it is the corresponding distance spectrum. In practical situations, a rectangular, i.e. constant, distance spectrum indicates a uniform spatial distribution of nuclide within the effective sample volume. If the energy spectrum were concave upward, the distance spectrum would be also, and if the energy spectrum were concave downward, the distance spectrum would be also. Hence, energy spectra that are concave upward, linear ramps, or concave downward strongly suggest the existence of distributions within the effective sample volume that decrease with depth, are constant, or increase with depth, respectively.

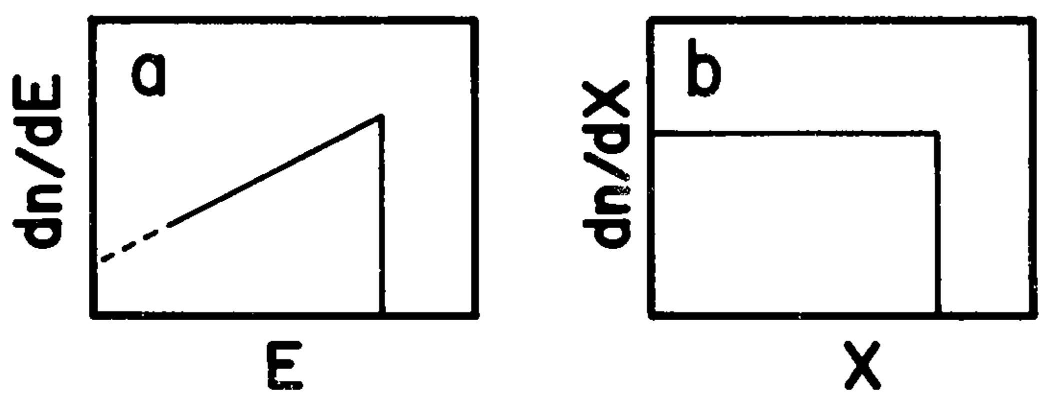

FIG. 1.-- Schematic representations of (a) energy and (b) distance spectra.

Autoradiography. For alpha detection, we use Eastman Kodak NTA emulsion plates in tight contact with 100-μm-thick bone sections. Emulsion allows a faint shadow of the section (Figure 2) to be recorded on the autoradiograph as a guide to establishing registration when the autoradiograph and section are viewed simultaneously through a single set of eyepieces connected to a pair of microscopes.[3] The section is stained with methyl green to increase its opacity for the shadow-casting process.

FIG. 2.-- An example of shadowing on NTA emulsion. Because the photographic image is negative, the shadow is light.

For fission fragment detection, a 100-μm-thick bone section laden with ^{239}Pu is placed in tight contact with a 300-μm-thick sheet of Lexan plastic, and the combination is exposed to thermal neutrons. Tracks are etched by floating the Lexan on 6N NaOH at temperatures between 40 and 90°C to avoid the introduction of visible artifacts on the underside of the Lexan sheet. The bone image[4] ensures registration between the pattern of tracks and the outline of the section.

Spatial Resolution. Of the three methods, alpha spectrometry has the greatest spatial resolution. Fission track autoradiography is second. When autoradiographs are carefully developed and viewed, the position of the track entry point in Lexan relative to the bone surface can be determined with an accuracy better than 5 μm. Since the fission fragments can originate at any depth in the bone section within range of the Lexan, the actual spatial resolution is somewhat poorer than 5 μm. With alpha track autoradiography, the difficulty of achieving truly precise registration limits the resolution greatly. The shadow edge is not always easy to detect and may not correspond precisely to the outline of the section because of penumbra and non-zero section thickness. Entry points are not easy to determine, especially for short tracks that lie nearly parallel to the emulsion surface with high grain density along their full length. The best resolution achievable is probably 20-30 μm except under extremely favorable circumstances.

Surface Deposit Thickness

Figure 3 shows the endosteal surface alpha spectrum of cortical bone from a person accidentally exposed to ^{241}Am (sample supplied by the U.S. Transuranium Registry). The spectrum peak is confined to a narrow range close to 5.49 MeV, the average energy of alpha particles emitted by disintegrating ^{241}Am. The alphas particles that created the peak lost little energy and traveled only a short distance through bone before being detected and could only have originated in deposits at or near the surface. The full width at half maximum of the peak (FWHM) divided by the alpha stopping power in bone provides an index of deposit thickness, which here equals 143 keV ÷ 134 keV/μm = 1.1 μm. Although the relationship between them is unknown, the index and the deposit thickness cannot differ greatly in value.

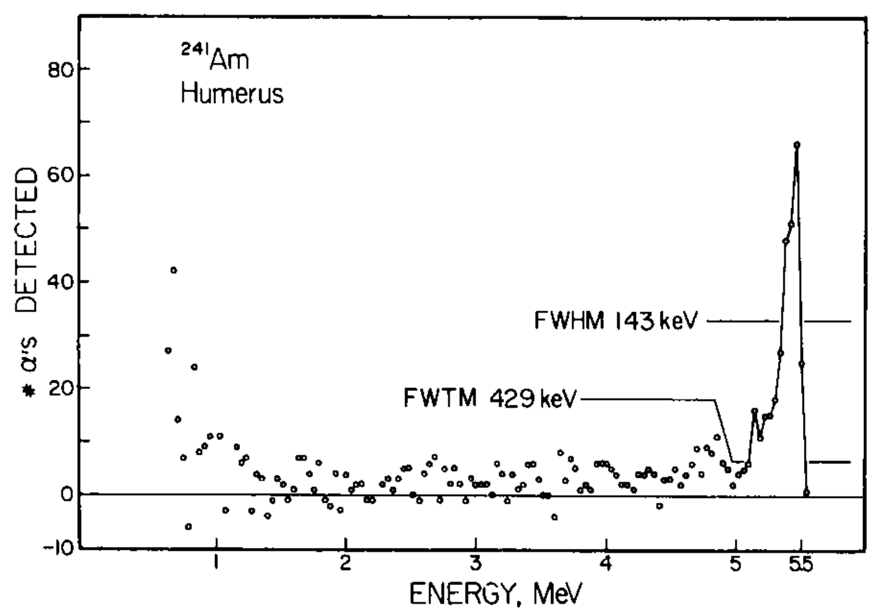

FIG. 3. Endosteal surface alpha spectrum of ^{241}Am in human bone.

The width of the peak at its base divided by the stopping power provides an upper limit on deposit thickness. Non-flatness of the bone surface, small sample-detector separation, and electronic noise from the pulse amplifiers in the data collection system widen the peak and guarantee that this quotient exceeds the deposit thickness. Since the spectrum tail obscures the base of the peak, the full width at one-tenth maximum (FWTM) is used as a practical alternative to the base width. All but a negligible fraction of the peak area is included within this energy interval, and the ratio of FWTM to stopping power defines a distance that is equal to, or greater than, the distance traveled by all but a negligible fraction of the particles contributing to the peak. For Figure 3, the full width at one-tenth maximum is 429 keV, and the equivalent distance is 3.2 μm.

Data for radionuclides deposited on the cortical endosteal surface are presented in Table 1. The data were obtained from spectra that varied widely in statistical precision. Since a more precise spectrum would be expected to yield a more precise index of deposit thickness, letters included in parentheses signify peaks in which the highest point was less than 100 counts (L), between 100 and 1000 counts (M), or in excess of 1000 counts (H). The letter B indicates a peak width that was significantly broadened by the fine structure of the alpha particle spectrum; for ^{228}Th, the principal emission energies are 5.42 and 5.34 MeV. Thus, the FWHM may be 0.08 MeV (80 keV) wider than if particles of a single energy were emitted in the decay of ^{228}Th. Fine structure is present with ^{239}Pu and ^{241}Am, but its effect is probably less pronounced. Because ^{212}Pb is a beta emitter, the thickness index and FWHM are based on observations of its alpha emitting daughter, ^{212}Po.

TABLE 1. Surface deposit thickness index.

Species	Nuclide	FWHM,[a] keV	Index, μm
Dog	^{212}Pb[b]	140(M)[c]	1.5
	^{224}Ra	133(H)	1.0
	^{226}Ra	178(H)	1.2
	^{228}Th	246(M,B)	1.8
Human	^{239}Pu	122(M)	0.87
	^{241}Am	143(L)	1.1

[a] Full width at half maximum.
[b] Based on the ^{212}Po daughter product.
[c] See text for explanation of letters in parentheses.

The similarity in values for the different nuclides suggests the existence of a single anatomical compartment in human and dog bone capable of binding all radionuclides at bone surfaces regardless of their chemical properties. This compartment may be the boundary zone, represented by the lamina limitans[5] in electron micrographs, between the thin layer of collagenous tissue that occurs at bone surfaces and the mineralized matrix.

Radium Distribution Near the Endosteal Surface

In the radiation protection literature, calculations of endosteal tissue dose values for bone volume seekers are based on the assumption that the radionuclide is uniformly distributed throughout bone.[1] Advantage has been taken of the high spatial resolution of alpha spectrometry to test this assumption. In the three subjects examined so far, the radium distribution near the bone surface has been quite nonuniform, with a pronounced tendency to rise to a maximum at the surface. Figure 4 shows a spectrum from this group. Although peaks reminiscent of those found for surface seekers are prominent (compare to ^{241}Am, Figure 3), this spectrum was recorded 39 years after first exposure, at a time when radium would be classified as a volume seeker. For contrast, the spectrum of a spatially uniform source, made by grinding ashed bone to a powder and mixing it thoroughly, is shown in Figure 5.[6]

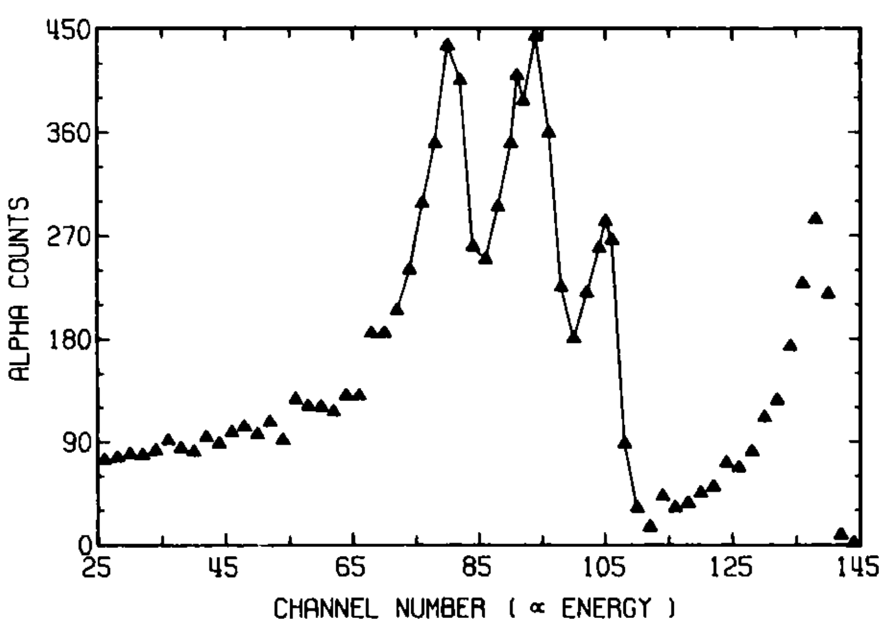

FIG. 4.-- Endosteal surface alpha spectrum of ^{226}Ra and its daughters in human bone 39 years after injection (Case 01-302). From the left, the peaks correspond to ^{226}Ra, ^{210}Po, ^{222}Rn, ^{218}Po, and ^{214}Po.

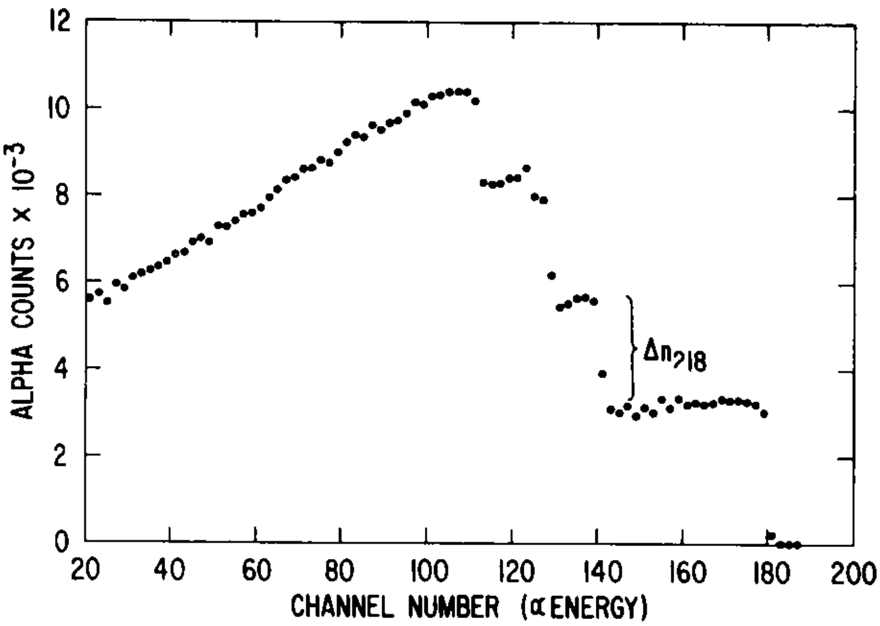

FIG. 5.-- Alpha spectrum of ^{226}Ra and its daughters uniformly distributed in ashed bone. From the left, the discontinuities correspond to ^{226}Ra, ^{210}Po, ^{222}Rn, ^{218}Po, and ^{214}Po.

Radium daughter product concentrations are usually different _in vitro_ than _in vivo_ because of the delay between death and measurement, and because ^{222}Rn retention is affected by changes in the water content of bone. The daughter product contributions must, therefore, be separated from the total spectrum. This can be performed electronically with alpha-gamma coincidence spectrometry or mathematically by stripping away the daughter product contributions.[7] Figure 6 compares the results of the two methods.

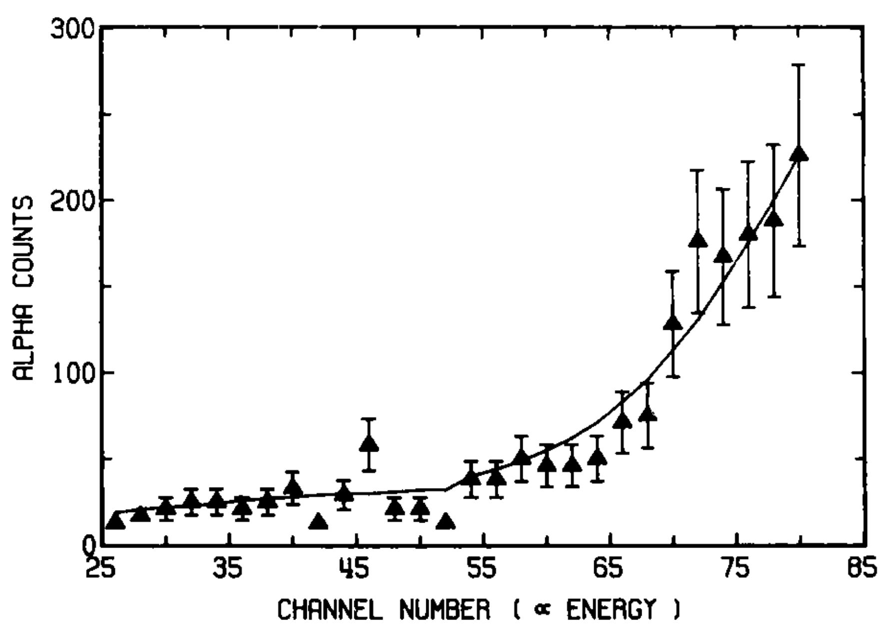

FIG. 6.-- The ^{226}Ra component from Figure 4 determined by coincidence counting (points) and independently by mathematical deconvolution (solid curve).

The sample-detector geometry can be calibrated through the use of standardized solutions. A gold foil cover is molded to the sample surface. A known quantity of solution is then spread over the foil and dried, and an alpha count is made to determine the fraction (g) of particle emission from the foil that is detected. For accuracy, the angular distributions of alpha particles from the foil and bone surface should be the same. This requirement is met sufficiently well when the sample-to-detector distancc exceeds the detector radius, and the largest sample dimension is less than the detector radius. If N_{226} is the number of ^{226}Ra alpha particles detected, N_{226}/g is the number of alphas emitted within the effective sample volume during the data collection period.

For dose-rate calculation, the endosteal tissue mass and (dn/dx)/g, the spatial distribution corrected for sample-detector calibration, are required. The latter can be computed from the distance spectrum, an example of which is given in Figure 7 for the ^{226}Ra component of Figure 6. The former

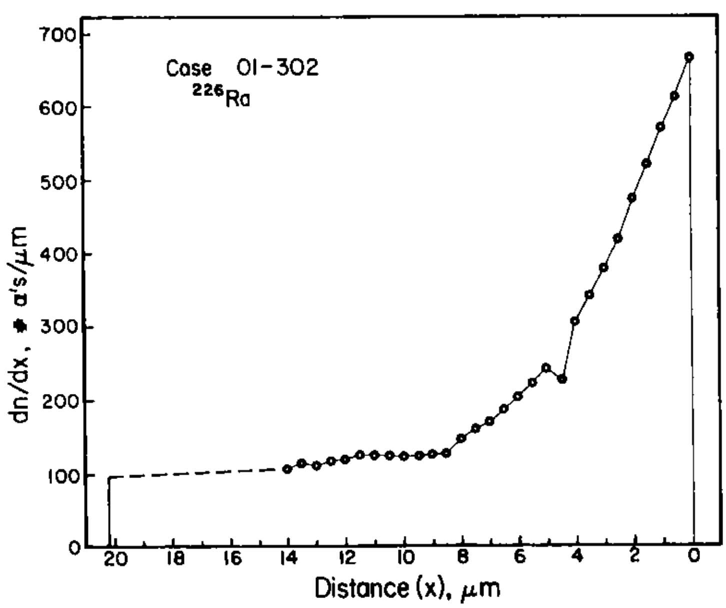

FIG. 7.-- The distance spectrum for the solid curve of Figure 6. The dashed portion is an extrapolation.

may be determined from the sample surface area, which can be estimated from a photograph of the sample surface or calculated from the three-dimensional coordinates of the surface measured with a light section microscope. A photograph gives the sample area projected onto a plane and, therefore, always underestimates the total area. Figure 8 shows a computer reconstruction of the sample surface from light section data. The area measured this way is 0.253 cm^2, and that measured from a photograph is 0.241 cm^2, a 5% difference.

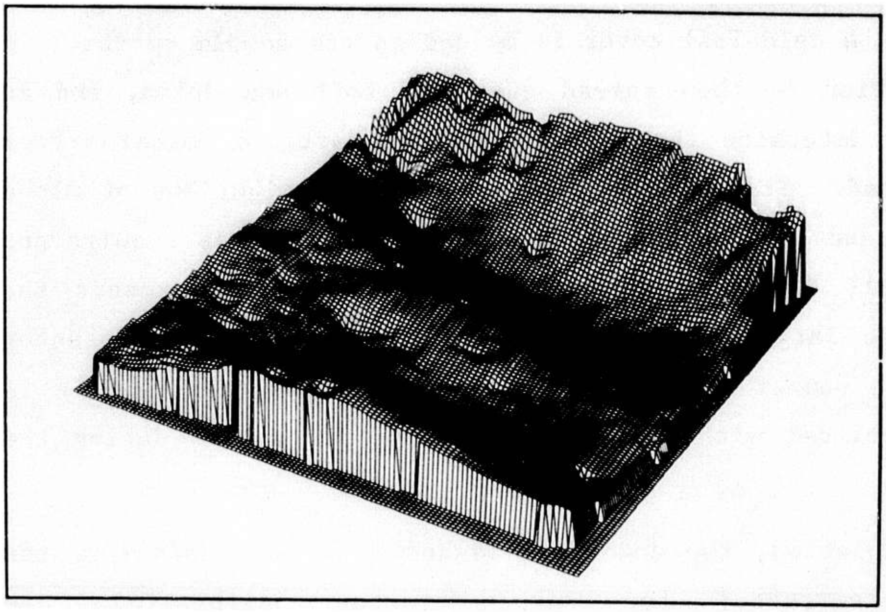

FIG. 8.-- Computer reconstruction of the cortical endosteal surface of the sample used to obtain the spectrum of Figure 4.

A plane bone surface is assumed in the dose calculations because the short range of the alpha particles makes the dose quite insensitive to surface irregularities. For the spatial distribution of Figure 7 and reciprocal stopping power approximated by a linear function of energy,[2] the dose rate, based on the calculations of Thorne,[8] averaged over a 10-μm-thick endosteal tissue layer is 0.49 rad/day, compared with 0.34 rad/day when a uniform concentration of radium is assumed.

Alpha Spectrometry in Conjunction with Autoradiography

The analysis of track lengths and angles can be used to determine the relative abundances of different radionuclides when mixtures[9,10] are present in tissue sections used for autoradiography. Alpha spectrometry offers a labor-saving alternative.

The spectra from bone sections labeled with ^{226}Ra are similar to the spectrum shown in Figure 5, but often have an additional narrow ^{210}Po peak. This peak is attributable to the fallout of airborne short-lived radon daughters during the storage of sections in closed containers or other environments from which radon released by the sections cannot readily escape. The long-lived beta emitter, ^{210}Pb, thus accumulates in thin deposits on the section surface, and its daughter, ^{210}Po, produces a peak in alpha spectra. An example is shown in Figure 9.

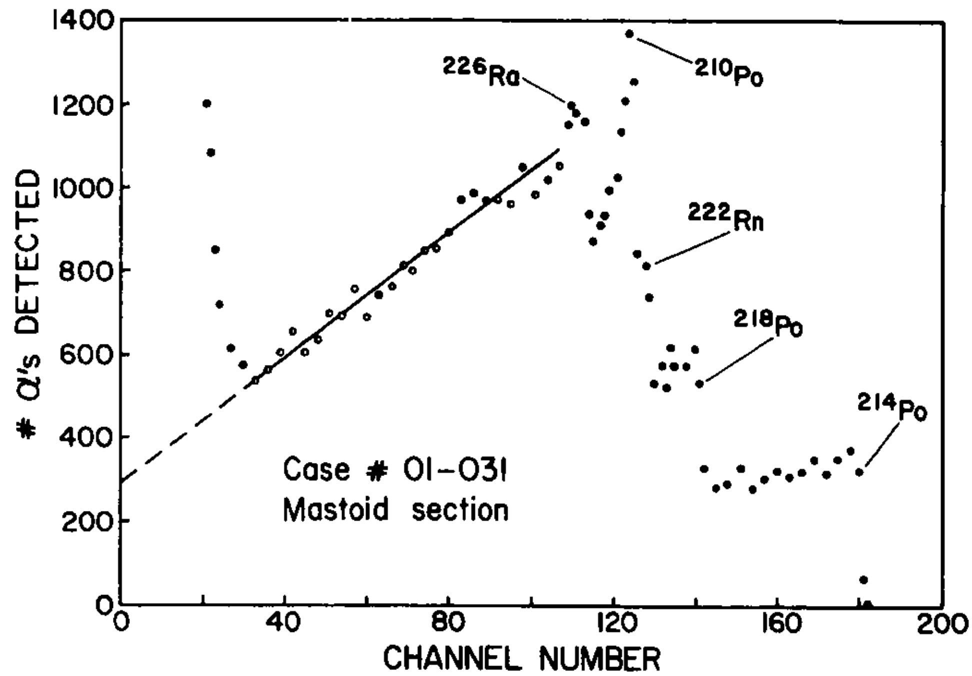

FIG. 9.-- Alpha spectrum of a mastoid bone section. The straight line is used in spectrum stripping.

The composite spectrum can be easily stripped because the nuclides within bone are uniformly concentrated as a function of depth in the effective sample volume and, therefore, all contribute linear ramp components with the same ratio of line slope to y-axis intercept. This ratio can be determined by fitting a straight line to the linear portion of the composite as shown in Figure 9. Linear ramps with the same ratio of slope to intercept can be fitted to the high-energy ends of the components, and the components can be subtracted out one by one. The components thus obtained for Figure 9 are shown in Figure 10.

The area beneath each component (Figure 10) gives the number of alpha particles contributing to the composite spectrum, and the ratio of component area to composite area gives, with reasonable accuracy, the fraction of tracks in an autoradiograph attributable to each nuclide (Table 2).

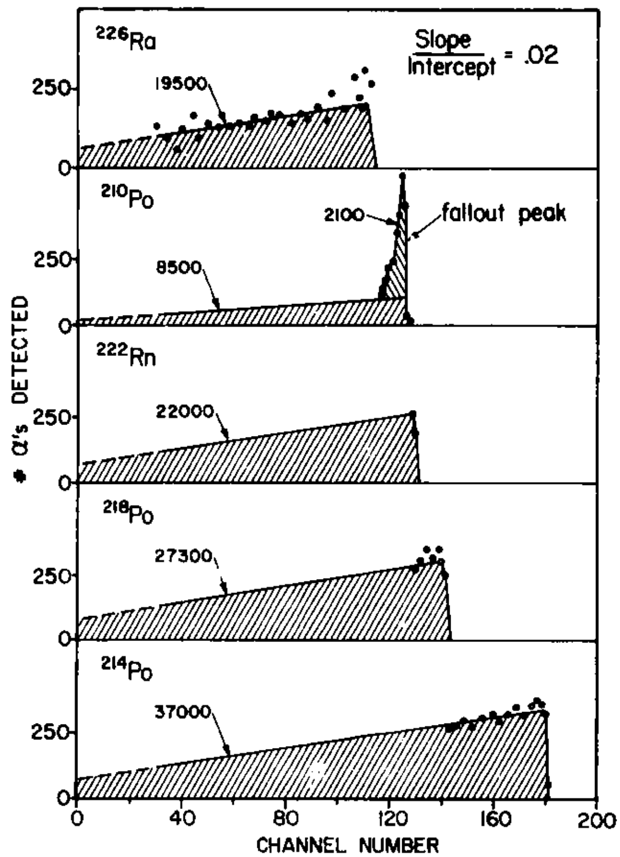

FIG. 10.-- The component spectra of Figure 9, obtained by spectrum stripping as described in the text.

TABLE 2. Percentages of alpha tracks in NTA emulsion expected to be produced by ^{226}Ra and its daughters

Nuclide	Best estimate	Ratio of areas
^{226}Ra	14	17
^{222}Rn	17	19
^{218}Po	23	23
^{214}Po	37	32
^{210}Po - total	9	9
- fallout	3	2

Radium Distribution in the Mastoid

The mastoid, middle ear, and sinuses have been prominent sites for carcinoma induction in radium cases.[11] It appears possible, with a combination of autoradiographic measurement, bone morphometry, quantitative histology, and modeling,[12-14] to determine the terminal dose rate and possibly the total lifetime dose to the epithelial tissues at risk within the mastoid and middle ear mucosa.

The epithelial cell dose is thought to be delivered by alpha particles emitted from the bone and air space,[11] as illustrated for a single sinus cavity in Figure 11. The presence of radioactivity in the air space results from the production of radon gas by radium deposits in bone and the subsequent translocation of most of the radon by atomic diffusion.

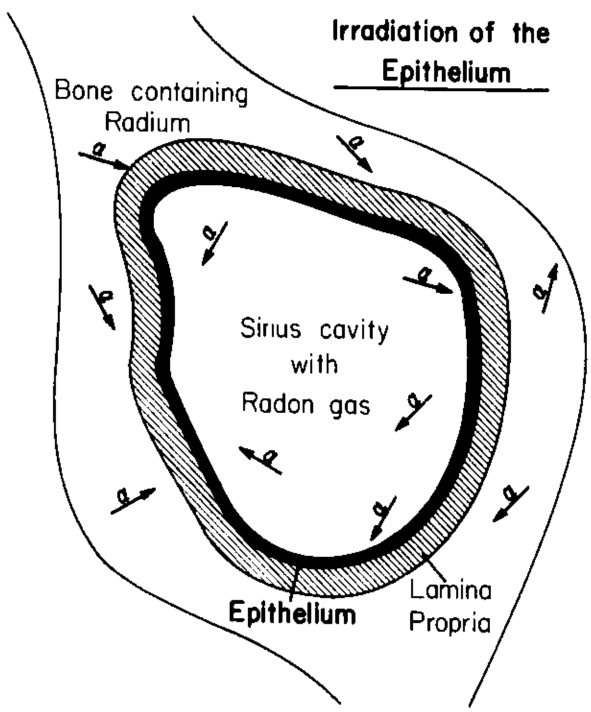

FIG. 11.— Schematic representation of a sinus showing epithelial irradiation by alpha particles from bone and from the air space.

The mastoid consists of a honeycomb of air cells (Figure 12), each irradiated similarly to the sinus. There are two morphologically distinct regions--the thin trabeculae-like bony septa that separate the air cells and the envelope of compact or cancellous bone that surrounds the air cell honeycomb. These regions differ also in their circulation. The envelope is liberally penetrated by blood vessels, while the bony septa are almost totally devoid of internal circulation. The nutrients for the septa are supplied from vessels in the mucosa.

These factors affect the fraction of the radon generated within the two regions that diffuses into the air cells. Nearly all free radon will diffuse from the septa, but only half of the free radon in the envelope will diffuse toward the air cells, and much of it will be cleared by the circulation before reaching the air cells. The two regions should, therefore, be treated as distinct sources of radon, and the partitioning of radium between these regions is quite important dosimetrically.

FIG. 12.-- A mastoid bone section viewed by microradiography. Some air cells are identified by labels (a).

Low-resolution autoradiographs have revealed the radium distribution pattern exemplified by Figure 13, in which the radioactivity concentration appears to be lower in the septa than in the envelope. Examinations of many autoradiographs from 15 subjects showed that 12 could be classified as having low septal concentrations. This phenomenon has been examined by quantitative autoradiographic measurements at randomly selected sites within mastoid bone sections.

FIG. 13.-- Autoradiographs of mastoid sections showing low septal and high envelope concentrations of ^{226}Ra and its daughters.

Radium specific activities estimated from track count data using an expression presented by Schlenker and Farnham[15] are given in Table 3. The data verify the conclusions drawn from the visual assessment of autoradiographs, although 14 of the 15 cases, rather than 12 of 15, show lower septal than envelope concentrations. The reason for the persistent difference between concentrations is unknown. One possibility is that blood perfusion of the envelope was much higher than that of the mucosal membranes lining the septa. Another possibility is that bone formation activity was greater in the envelope at the ages of exposure (first exposure occurred between 14 and 57 years).

Whatever the explanation, it is clear that the difference in concentrations affects the assessment of radiation dose, which, in the absence of direct observations, would be computed on the assumption that the specific activity in both regions was the same and equal to the average measured in the skeletons of these subjects. This would lead to a large error in most cases.

<u>Factors Affecting Plutonium Specific Activity</u>

Substantial differences in plutonium specific activity have been observed between different parts of the skeleton[16] in a subject from the Langham et al. injection series[17] for which there are autoradiographic data.[18,19] Because plutonium is a surface seeker, variation in the bone surface area per gram would be expected to affect specific activity. Other important factors would be the amount of buried bone surface labeled by plutonium and the surface concentration.

Figure 14 shows a fission track autoradiograph from the subject in question verifying the surface deposition of plutonium. The arrow points to a plutonium-labeled buried bone surface near an existing surface.

TABLE 3. ^{226}Ra specific activities in mastoid septa and envelopes measured by autoradiography and the skeletal average measured by gamma-ray detection.

Case number	^{226}Ra, pCi/g wet bone		
	Septa	Envelope	Skeletal average
00-006	590	790	920
00-009	390	1100	720
00-027	610	840	630
01-011	320	620	2200
01-014	150	360	630
01-031	120	190	310
01-046	140	200	240
01-145	110	1400	2000
01-562	940	1800	3500
01-613	70	200	210
03-209	30	130	240
03-240	320	1200	1600
10-644	1700	1600	1700
10-831	60	150	150
10-840	80	94	130

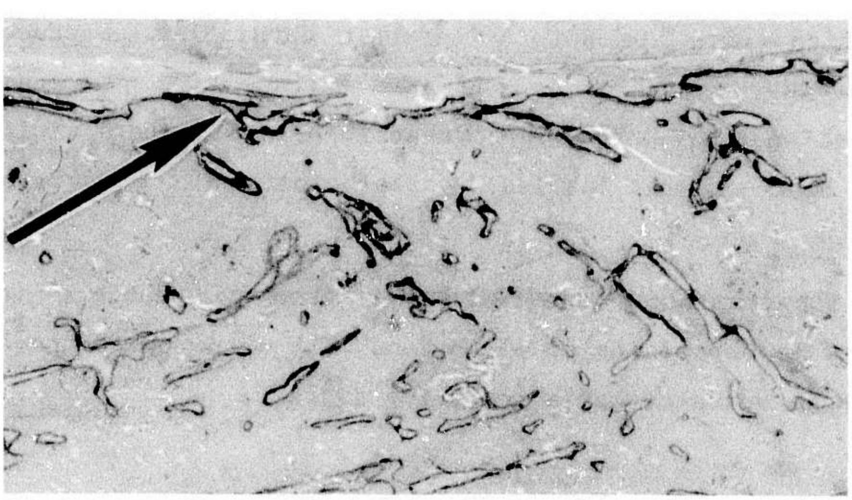

FIG. 14.-- Autoradiograph of ^{239}Pu in the iliac crest. The arrow points to a plutonium-laden buried bone surface.

Larsen found the specific activity of plutonium in bone pieces analyzed radiochemically to be an order of magnitude higher in parts of the axial skeleton than in parts of the appendicular skeleton.[16] To determine how surface area, buried surface area, and surface concentration produce such a difference, the specific activity must be expressed in terms of these quantities. The amount of plutonium on the surfaces and buried surfaces of bone is approximately $S(1 + f)C$, where S is the surface area, f times S is the area of plutonium-labeled buried surface, and C is the surface concentration. The amount of bone ash is $\rho_{ash}V$, where V is the bone volume and ρ_{ash} is the ash content per unit volume. The specific activity is, therefore, $(S/V)(1 + f)(C/\rho_{ash})$. The ratio of specific activities between two parts of the skeleton would be $[(S/V)_2/(S/V)_1][(1 + f_2)/(1 + f_1)][C_2/C_1]$.

The surface-to-volume ratio, S/V, is calculated from the perimeter to area ratio (P/A) measured from the bone section image on the autoradiograph. For cancellous bone, $S/V = (4/\pi)(P/A)$, and for compact bone, $S/V = P/A$. The ratio, f, of buried to existing surface is measured by scanning across the autoradiograph and counting the number of times a surface or a plutonium-labeled buried surface is encountered. Concentration is determined by fission track counts and calibration factors.

Average values for S/V, 1 + f, and C for three anatomical regions are presented in Table 4. Specific activity ratios calculated as indicated above and those based on Larsen's radiochemical data[16] are compared in Table 5.

TABLE 4. Surface-to-volume ratio, ratio of buried to existing surface, and surface plutonium concentration in Case 40-010.

Region	S/V, cm^{-1}	1 + f	C, pCi/cm^2
Axial skeleton	213	1.41	1.0
Proximal femur	161	1.10	0.36
Long bone midshafts	35	1.09	0.25

TABLE 5. Ratios of specific activity in different regions of the skeleton, based on autoradiographic and radiochemical data.

Regions	Autoradiographic	Radiochemical
Axial/femur	4.7	3.6
Axial/midshaft	31	31
Femur/midshaft	6.7	8.6

The agreement between the autoradiographic and radiochemical observations is good, verifying that S/V, f, and C are the principal determinants of specific activity in this subject.

By considering the ratios of individual factors, i.e., $(S/V)_2/(S/V)_1$, $(1 + f_2)/(1 + f_1)$ and C_2/C_1, one can establish the relative importance of each in determining the specific activity ratio. These ratios are presented in Table 6. The difference in surface concentration clearly is the most important determinant of the difference in specific activities between the axial skeleton and proximal femur. The difference in surface-to-volume ratios is the most important determinant of the difference in specific activities between the axial skeleton and long bone midshafts and between the proximal femur and long bone midshafts. Overall, the differences in surface-to-volume ratios and in concentrations are more important than the difference in the amount of buried bone surface.

TABLE 6. Ratios of the principal factors that affect the plutonium concentration in bone.

Regions	$\frac{(S/V)_2}{(S/V)_1}$	$\frac{1 + f_2}{1 + f_1}$	$\frac{C_2}{C_1}$
Axial/femur	1.32	1.28	2.78
Axial/midshaft	6.09	1.29	4.00
Femur/midshaft	4.60	1.01	1.44

Summary

This review of work at Argonne National Laboratory has dealt with the microdistribution of radium and plutonium in human bone, with emphases on the alpha-spectrometric method of measurement, the determination of deposit thickness for bone-surface seekers, the establishment of radium concentration close to the endosteal surface, the use of alpha spectrometry as a labor-saving method for determining the relative abundance of radionuclides in bone sections used for autoradiography, the measurement of radium concentration within different portions of the mastoid bone, and the explanation of why differences occur in specific activity of plutonium within different portions of the skeleton.

Some of the findings reported are that alpha spectrometry offers particularly high spatial resolution and is therefore especially well suited to the measurement of radionuclide concentrations at, and adjacent to, the endosteal surfaces. Surface deposits for isotopes of lead, radium, and the actinides are of the order of 1 μm thick. Volume deposits of ^{226}Ra can be quite nonuniform near bone surfaces, leading to endosteal tissue dose rates that are higher than expected under the assumption of uniform volume concentration normally used for radiation protection calculations. The bony septa of the mastoid air cell system in high-dose radium cases tend to be depleted in radium relative to the envelope of the mastoid bone surrounding them, and this is expected to have a significant influence on the dosimetry of the mastoid epithelia. A combination of autoradiographic and morphometric measurements indicates that specific activities of plutonium are higher in the axial than in the appendicular skeleton, primarily because the axial skeleton has higher bone surface-to-volume ratios and higher bone surface concentrations of plutonium.

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RADIUM-INDUCED DENTAL CHANGES IN HUMANS AND BEAGLES: A COMPARATIVE MICRORADIOGRAPHIC STUDY

J. E. Farnham, J. P. Morgan,* R. R. Pool* and T. Miyabayashi*

Microradiographs made from thin sections of teeth of humans carrying skeletal deposits of ^{226}Ra and ^{228}Ra and of beagles injected with ^{226}Ra showed similar patterns of change with age. The patterns consisted of the presence of remodeling units of alveolar bone that extended across the gomphosis and involved the cementum and dentine. This is not described as a normal aging change in humans or beagles.

Introduction

The presence of radioactivity in the teeth of individuals following the intake of radium has been well documented.[1] Less is known about the pathologic changes within the teeth. We report here results of a preliminary effort to compare dental changes in humans and beagles whose skeletons contain high levels of radium. Part of the protocol in the human studies was to examine the teeth of the living and deceased radium cases using microradiographic and autoradiographic methods. Because a part of the protocol at LEHR also was to examine the teeth of selected dogs with ^{226}Ra intoxication using microradiography, a collection of microradiographs of beagle teeth was available for comparison studies. This report presents the early results of this comparison.

Materials and Methods

Exposure data and causes of death for the humans and beagles from whom teeth were obtained are presented in Table 1. The human bone doses were calculated using a bone mass of 5 kg for males and 3.4 kg for females.[2]

For these studies, microradiographs were made of 100 μm thick, undecalcified, plastic embedded, polished tooth sections, using Kodak 649-0 glass spectroscopic plates with a single photographic emulsion. Exposures were made using 10 kVp x-rays at 200 mA-min. Sufficient alveolar bone was

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Table 1. Exposure data and causes of death for humans and beagles in the tooth study.

ID number	Sex	Age at first exposure (yr)	Duration of intake (wk)	Age at death (yr)	Systemic intake (μCi)		Average bone dose at death (rad)	Cause of death
					^{226}Ra	^{228}Ra		
Humans								
00-006	F	15	128	27	357	808	17,300	Sarcoma, pelvis
00-008	M	25	598	48	525	682	13,100	Carcinoma of lung
00-009	F	18	266	28	295	504	9,240	Placenta previa
00-020	M	24	676	37	67	49	640	Aplastic anemia
00-022	F	28	377	35	752	807	10,900	Acute anemia
00-023	F	17	65	29	1016	116	10,200	Sarcoma, pelvis
00-027	F	16	130	40	505	615	19,400	Radium poisoning
01-040	F	16	60	22	412	2585	33,200	Anemia
03-201	F	13	+	54	805	--	14,300	Osteogenic carcinoma [sic]
03-473	F	18	156	61	311	—	5,580	Coronary thrombosis
Dogs								
R50M03	M	1.19	14	4.1	100	--	12,920	Osteosarcoma, pelvis
R50M04	M	1.19	14	3.9	100	—	11,382	Osteosarcoma, nasal bone
R50M05	M	1.19	14	5.2	100	--	20,994	Osteosarcoma, humerus (L)
R50M14	M	1.19	14	3.3	100	—	13,260	Undetermined
R50M37	M	1.19	14	2.3	100	--	7,388	Undetermined

+ = Exposure duration unknown.

available for examination in all the beagles and in the human cases 00-008, 00-020, and 00-023. Microradiographs of human and beagle teeth showing radiation-induced changes were compared with a series of microradiographs of a normal aging population of beagles.

Results and Discussion

Microradiographic changes were noted in the alveolar bone and periodontal space in both beagles and humans. Other microradiographic changes were noted in the cementum, dentine and pulp cavity. The severity of the changes in the two species is compared in Table 2. Specific changes noted in each human case are presented in Table 3.

TABLE 2. Comparison of the degree of microradiographic change in human and beagle teeth.

	Humans	Beagles
Alveolar bone		
1. Presence of unfilled resorption cavities	+ to ++	+ to ++
2. New bone production resulting in filling of the periodontal space	+	++
Periodontal space		
1. Narrowing due to alveolar bone production	+	++
2. Bridging by alveolar bone production	+	0 to +++
Cementum		
1. Replacement by osteonal bone	+	+++
2. Presence of canals (cutting cones)	+	0 to +
3. Surface erosion by Howship's lacunae	+++	+++
Dentine		
1. Presence of resorption cavities	+ to +++	0 to +
2. Replacement by osteonal bone	+ to +++	+++
3. Surface erosion by Howship's lacunae	0 to +	+

0 = not seen; + = minimal; ++ = moderate; +++ = marked

TABLE 3. Microradiographic changes noted in radium-damaged human teeth.

CHR case number	Alveolar bone			Periodontal space		Cementum			Dentine		
	Amount available	Resorption cavities	New bone	Narrowing	Bridging	Bony replacement	Cutting cones	Howship's lacunae	Resorption cavities	Bony replacement	Howship's lacunae
00-006	f	–	–	0	SL	0	0	+	0	0	0
00-008	S	+	0	0	0	0	0	0	0	0	+
00-009	f	–	–	0	SL	0	0	+	+	0	0
00-020	S	+	0	0	0	0	0	0	0	0	0
00-022	N	–	–	–	–	0	+	+	0	0	+
00-023	S	+	+	+	+	+	+	0	+	+	0
00-027	f	–	–	0	SL	0	0	+	SL	0	0
01-040	f	–	–	0	0	0	0	+	0	0	0
03-201	f	–	–	0	0	+	+	+	+	+	+
03-473	f	–	–	+	+	0	+	+	+	+	+

f = small fragment; N = none; S = sufficient for study;
0 = not present; SL = only a slight amount present; + = change noted;
– = insufficient amount for study.

The pattern of change within the human teeth varied markedly, presumably because of the wide range in the age at first exposure and in the survival time. The pattern of change within the teeth of the beagle was much less variable, perhaps because all the dogs were injected with ^{226}Ra at the same age. Neither the survival time nor the bone dose appeared to correlate directly with the degree of structural alteration.

The pattern of bone production leading to effacement of the periodontal ligament, cementum, and dentine of the tooth appeared to originate from normal remodeling activities in the adjacent alveolar bone. For undetermined reasons, the remodeling units of the alveolar bone extended across the gomphosis and involved the cementum and dentine of the tooth. In one human tooth, more than 50% of the dentine was replaced by bone tissue.

Replacement of dentine by bone tissue has not been reported to be one of the normal aging changes in the human tooth. While minor replacement of the cementum and dentine by bone tissue in teeth of aging control beagles was recognized, the pattern of bone tissue replacement seen in the R50 dogs far exceeds normal aging changes with respect to the quantity of bone formed. In addition, the pattern of dentine replacement by bone tissue begins at a much younger age in the dogs with ^{226}Ra intoxication.

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AN UNEXPECTED PATTERN OF HUMAN CELL SURVIVAL FOLLOWING ALPHA-PARTICLE IRRADIATION IN VITRO

R. A. Schlenker, E. G. Thompson and B. G. Oltman

Normal human fibroblasts were irradiated with alpha particles. Cell survival was significantly higher when the average linear energy transfer of the alpha spectrum was higher, contrary to expectation.

Introduction

A study of the factors that may influence the induction of bone cancer by alpha particles is underway. Physical quantities such as the distribution of alpha-particle energies and the angle at which the alpha particles impinge on the cells are currently being investigated. This report presents data on human cell survival following irradiation with alpha particles having a broad distribution of energies.

Materials and Methods

The cells used in these experiments were IMR-90, a strain of normal human lung fibroblasts originally cultured from a 16-week-old female fetus, and supplied by the Institute for Medical Research, Camden, New Jersey. Ampules of cells stored in liquid nitrogen were thawed and the cells dispersed in a complete medium consisting of RPMI-1640, 20% fetal bovine serum, 1% L-glutamine, and 1% garamycin. Cells were inoculated into plastic Petri dishes and incubated at 37°C in an atmosphere consisting of 5% O_2, 7% CO_2, and the balance made up of nitrogen, water vapor, and the minor constituents of normal air. The relative humidity exceeded 95%. The cells were grown to confluence and then passaged. At least two passages were made before exposure to alpha particles.

Twenty-four hours prior to irradiation, cells were trypsinized and inoculated into standard 60 x 15 mm plastic Petri dishes. Just before irradiation, all dishes were removed from the incubator and placed in the hood, at room temperature, where they remained until the irradiations had been completed. The dishes were irradiated one at a time in the chamber shown in Figure 1. To ensure that the cells were bare during irradiation, the medium was removed, and the cells were rinsed twice with phosphate-buffered saline. Following removal of the second rinse, the dishes were tilted at a high angle and allowed to drain for 60 seconds. The residual saline that collected at the lowest point of the tilted dishes was removed, and each dish was placed upside down in the opening at the top of the chamber, as indicated in Figure 1. After delivery of the required dose, the dishes were removed, the medium was replaced, and the dishes were allowed to stand in the hood until all irradiations had been completed. They were then returned to the incubator for two weeks, after which the cells were fixed with methanol and stained with Giemsa. The stained dishes were examined, and colonies containing 50 cells or more were scored.

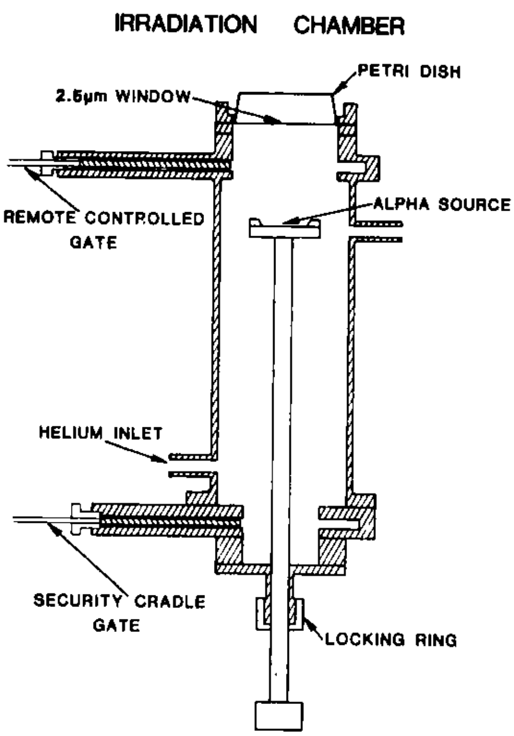

FIG. 1.-- Cross-sectional view of the chamber used for alpha-particle irradiations. A Petri dish containing cells is placed upside down at the top of the chamber. The cells are irradiated by alpha particles emitted from the alpha source (^{241}Am). The chamber interior is filled with helium gas, which absorbs part of the energy and allows control over the energy of the particles entering the cell layer. A gate is opened and closed to control the duration of exposure. A 2.5-μm window of Hostaphan (polyethylene terephthalate) separates the chamber interior from the exterior.

Fractional survival was expressed as the number of colonies corrected for plating efficiency, divided by the number of cells attached to the Petri dish bottom just prior to irradiation. To determine the latter number, some dishes were not irradiated, but were fixed and stained at the time the irradiations were carried out, and the numbers of cells attached were determined by direct count under the microscope.

The plating efficiency was determined from colony counts in dishes that were incubated for two weeks without irradiation. Plating efficiency was defined as the number of colonies divided by the number of cells attached.

There were three replications of the experiment. For each one, the Petri dishes were divided into two groups irradiated with the source at a different distance from the cell monolayer. The energy lost by alpha particles traveling through the helium gas that filled the irradiation chamber was different for the two groups. The spectrum of alpha-particle energies with which the cells were irradiated was therefore different also. The spectra at the centers of the Petri dishes are shown in Figure 2. The maximum energies were 2.9 and 3.6 MeV.

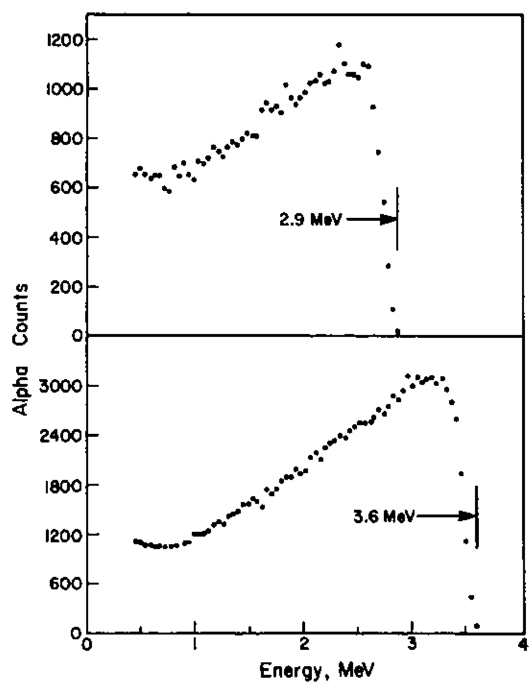

FIG. 2.-- Alpha-particle spectra at the center of the cell layer for the two groups of Petri dishes. The difference in maximum energies (2.9 and 3.6 MeV) was produced by placing the source at different distances from the Petri dish.

Results and Discussion

Fractional survival as a function of dose is shown in Figure 3. The exponential survival curves were fit to the data by eye. The mean lethal doses for the 2.9 and 3.6 MeV spectra, measured from the graphs, are 48 and 76 rad, respectively. The difference between the two curves is statistically significant at the 5% level.

Survival would be expected to vary inversely with linear energy transfer (LET). Since the average LET of the 2.9-MeV spectrum is higher than that of the 3.6-MeV spectrum, the survival should be lower; however, the opposite was observed. A possible explanation is that low-energy particles within both spectra fail to penetrate the nuclei sufficiently to kill the cells. The proportion of the spectrum with energies below the minimum required for cell killing would be greater for 2.9 MeV than for 3.6 MeV. Therefore, if the effect of LET were small, the 2.9-MeV spectrum would be expected to yield the higher survival, as observed. Other explanations, including technical artifact, are being sought.

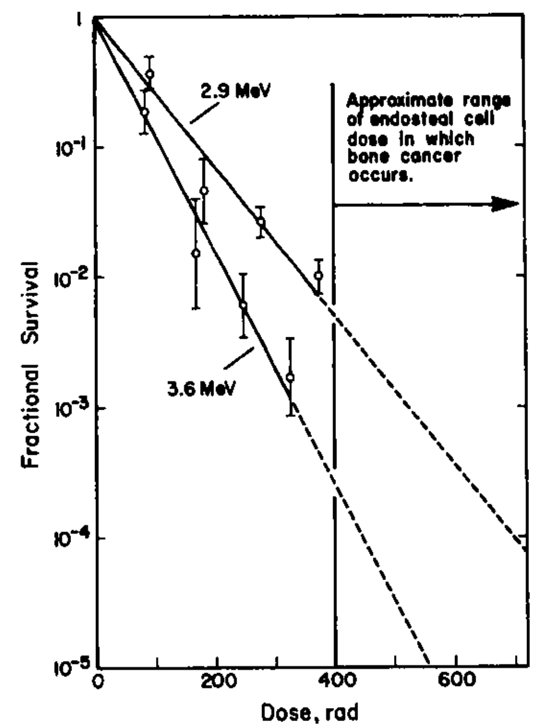

FIG. 3.-- Fractional survival as a function of cell dose. The data from three replications of the experiment are pooled. The error bars associated with each point represent the 68% confidence interval estimate for the fractional survival.

The broad distributions of alpha-particle energy (Figure 2) are similar to the distributions that would be obtained from bone volume seekers. The approximate range of endosteal cell doses associated with bone cancer induction in humans is shown in Figure 3. In this region, the survival curves differ by factors of 20 or more. Since cells must survive in order to produce tumors, there could be a marked difference in the probability of bone cancer induction for the two different spectra, i.e., an individual irradiated with alpha particles having an energy distribution like that of the 2.9-MeV spectrum of Figure 2 could be at higher risk because more of that person's cells would survive. Since the endpoint energies for different radionuclides in bone volume differ considerably, it is possible that these cell culture results have practical implications for the interpretation of bone cancer incidence data from humans. The experiments are being continued to gain a deeper understanding of their significance.

ACTIVITY RATIOS OF THORIUM DAUGHTERS IN VIVO*

R. E. Toohey, J. Rundo, J. Y. Sha, M. A. Essling, J. C. Pedersen,† and J. M. Slane§

A computerized method of least squares fitting has been used to analyze the ^{228}Ac and ^{212}Pb-^{212}Bi and daughter γ-ray spectra obtained *in vivo* from 133 former workers at a thorium refinery. In addition, the exhalation rate of ^{220}Rn was determined for each subject and expressed as pCi of emanating ^{224}Ra. This value was added to the ^{212}Pb value determined from the γ-ray measurements to obtain the total ^{224}Ra present, and the ratio of ^{224}Ra to ^{228}Ac was calculated. Values of the ratio ranged from 0.52 ± 0.32 to 2.1 ± 1.7, with a weighted mean of 0.92 ± 0.17. However, it appears that the ratio observed in a given case is characteristic for that case alone; the computed mean value may not be meaningful. The least squares fitting procedure and the overall calibration of the counting system were validated by comparing measurements of ^{224}Ra in the lungs of one subject postmortem with results obtained from the same subject *in vivo*.

Introduction

In our studies of the health effects of thorium exposure on workers, most of the internal dosimetry is based on external measurements of body radioactivity *in vivo*. These measurements determine, through γ-ray spectrometry, the body content of ^{212}Pb-^{212}Bi and daughters, and through breath collection, the amount of ^{220}Rn exhaled.[1] The latter measurement reveals the amount of ^{224}Ra that can be considered to be freely emanating, and we assume that the ^{212}Pb is in equilibrium with the non-emanating ^{224}Ra. The emanating and non-emanating parts of the ^{224}Ra are summed to give the total body content.

Unfortunately, this method establishes only a lower limit for the body contents of ^{228}Th, ^{228}Ra, and ^{232}Th. If, however, enough γ-ray activity (more than about 0.1 nCi) from thorium daughters is present *in vivo*, the ^{228}Ac activity can be determined, and, if we assume equilibrium, we also determine

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the ^{228}Ra body content. Consequently, the ratio of ^{224}Ra to ^{228}Ra can be established.

Determination of the ^{232}Th content can only be made postmortem via radiochemical analyses. When enough cases are analyzed to establish the $^{228}Ra/^{232}Th$ ratio, we will apply this factor to the results of analyses *in vivo*. Since, however, many fewer cases will be available for examination postmortem than *in vivo*, the $^{228}Ra/^{232}Th$ ratio is critical. If we find that this ratio varies significantly from subject to subject, we will attempt to determine the relationship of the $^{224}Ra/^{228}Ra$ ratio to the $^{228}Ra/^{232}Th$ ratio. From this relationship, then, we can still estimate the amount of ^{232}Th present *in vivo*.

Method

Gamma-ray spectra were collected with large (290 mm x 100 mm) NaI(Tl) crystals positioned above and below the thorax of each subject lying supine on a flat bed. The spectra were analyzed by a computer-based method of least squares in which the observed spectrum (after background subtraction) was treated as a linear combination of standard spectra stored in a computer library. The program, named "GASP", was developed at AERE Harwell[2] and has been adapted for use at Argonne. The advantage of this program is that it uses all the information in the observed spectrum, including scattered as well as primary γ-ray counts.

Standard spectra of ^{40}K and ^{137}Cs were obtained from polyethylene bottles filled with water solutions of either isotope and arranged in anthropomorphic configurations. The standard spectra from the thorium chain were obtained by placing point sources of either ^{232}Th or ^{228}Th at many different positions in the "lung" region of a simple thorax phantom originally developed by Miller.[3] The phantom was composed of masonite ("presdwood") and contained intervening air spaces to represent the lower density of lung tissue. The spectra from ^{232}Th and ^{228}Th, each with its daughters in equilibrium, are shown in Figure 1. Each spectrum was supplied as a standard to the fitting procedure. The amounts of ^{228}Ac and ^{212}Pb in the spectrum from a subject were computed as follows: to fit the region around 0.91 MeV (a ^{228}Ac γ ray), the program used the ^{232}Th spectrum. If the daughters of ^{228}Ac were not in equilibrium *in vivo*, then the region around 2.6 MeV (the ^{208}Tl γ ray, assumed to be in equilibrium with ^{212}Pb) contained more or fewer counts in the resulting fit than were observed in vivo. The program subtracted or added the appropriate amount of the ^{228}Th spectrum so as to obtain a good fit at 2.6 MeV, while still fitting the 0.91 MeV region. In practice, the entire observed spectrum from 0.3 to 2.8 MeV was used until the best fit was obtained. Consequently, the activity of the ^{232}Th standard found by the fitting routine was taken as the amount of ^{228}Ac present in vivo, and the algebraic sum of the activities of the ^{232}Th and ^{228}Th standards was taken as the amount of ^{212}Pb present in vivo. If the fitted amounts of ^{232}Th or ^{228}Th were not statistically significant (i.e., values less than their associated errors), the case was rejected. Finally, as mentioned above, the emanating ^{224}Ra content was added to the ^{212}Pb content to obtain the total ^{224}Ra, and the ratio of ^{224}Ra to ^{228}Ac was computed.

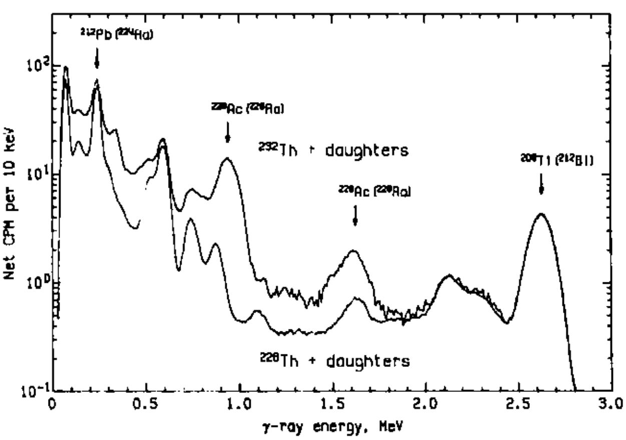

FIG. 1.— The γ-ray spectra of ^{232}Th and ^{228}Th, each in equilibrium with its daughters, normalized at the 2.61-MeV peak of ^{208}Tl.

The fitted spectrum and the observed data from case L-1167 are shown in Figure 2. The validity of the fitting procedure was determined by postmortem analyses of the amount of thorium in one patient (L-1521), to be discussed below, and also by the observation that the mean potassium content of this group of subjects was determined to be 0.20 ± 0.03 % of body mass, and the mean ^{137}Cs/K ratio was 7.9 ± 3.9 pCi/g. The former value is that for "reference man",[4] and the latter value is typical of that observed for other groups of subjects at other laboratories.[5,6]

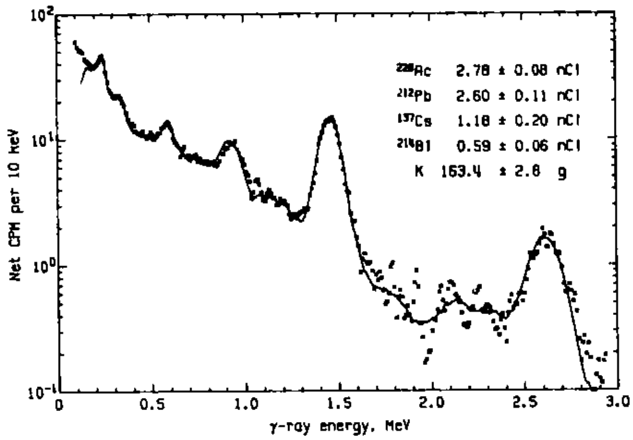

FIG. 2.-- Data observed <u>in vivo</u> (solid dots) and least squares fit (smooth curve) for case L-1167.

Results

When the procedure was applied to the spectra obtained from the 134 individuals who contained more than 0.1 nCi ^{212}Pb in the thorax (the maximum content observed was 2.9 ± 0.1 nCi), fitted values of the $^{224}Ra/^{228}Ac$ ratio ranged from 0.52 ± 0.32 to 2.1 ± 1.7, with a weighted mean of 0.92 ± 0.17. The variance ratio was 0.64 and the value of χ^2 was 15.4, indicating that a single population was sampled. The distribution of values of the ratio is shown in Figure 3. It appears that in most cases, some ^{224}Ra was being excreted following its production from ^{228}Th.

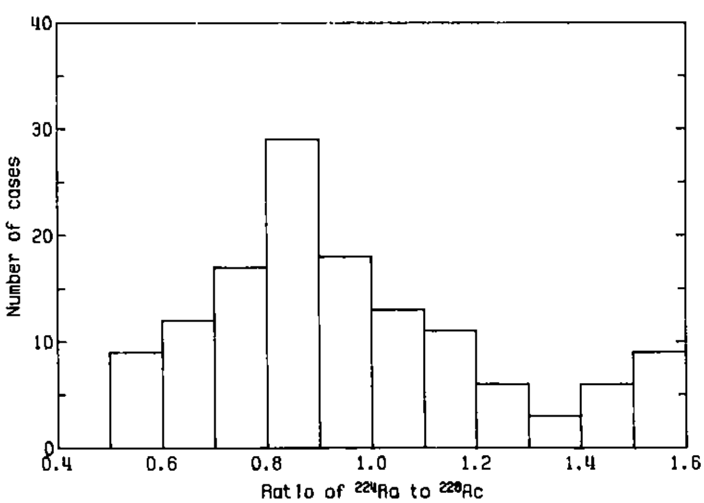

FIG. 3.-- Histogram of the values for $^{224}Ra/^{228}Ac$ for 134 former thorium workers.

One feature of the data is that over one-third of the values exceed 1.0, although only five of them exceed 1.0 by more than one standard deviation. The weighted mean for the 45 values exceeding 1.0 is 1.09 ± 0.22. Although this value is not significantly different from the mean for all cases, we will look carefully at work histories in relation to observed $^{224}Ra/^{228}Ac$ ratios to investigate the possibilities that exposures to ^{228}Ra or to ^{228}Th (enriched relative to ^{232}Th) occurred.

Several cases for whom repeat measurements are available show decreases in thorax content of ^{212}Pb with half-times of a few years, but the majority of these cases, extending across all ranges of the $^{224}Ra/^{228}Ac$ ratio, show little or no decrease in thorax content over periods of three to five years. A few cases actually show increases in thorax content of ^{212}Pb over the period of repeat measurements, and one even shows a concomitant increase in the $^{224}Ra/^{228}Ac$ ratio, suggestive of the growth of ^{228}Th _in vivo_ from an exposure to ^{228}Ra.

At the other end of the ratio scale, 38 cases had values below 0.8, suggestive of prior exposure to freshly separated thorium. At the time of measurement _in vivo_, the ^{228}Th activity may have decreased and not as yet been replenished by growth from newly formed ^{228}Ra. Again, a careful consideration of work history and time elapsed between exposure and measurement will be required. These low values could equally well be due to loss of ^{224}Ra _in vivo_.

As shown in Figure 4, extreme values of the $^{224}Ra/^{228}Ac$ ratio (less than 0.8 or greater than 1.20) are associated with lower amounts of radioactivity in the thorax and so are less reliable.

Validation of this method and determination of the $^{228}Ra/^{232}Th$ ratio depends on analyses of postmortem tissue samples. To date, samples are available from only four patients, only one of whom had also been examined _in vivo_. Results from this case (L-1521) postmortem confirmed the results _in vivo_, which had shown a $^{224}Ra/^{228}Ac$ ratio of 0.88 ± 0.14. The lungs and thoracic lymph nodes obtained at autopsy were placed in a reproducible geometry under one of the NaI(Tl) crystals used for measurements _in vivo_, and their γ-ray spectra were recorded beginning 12 hours postmortem and continuing almost daily for four weeks. The data shown in Figure 5 are the ratios of counts in the 2.61-MeV band (^{208}Tl) to those in the 0.91-MeV band (^{228}Ac), and the smooth curve is a fit to the growth of ^{224}Ra, predicting a $^{224}Ra/^{228}Ac$ ratio extrapolated to the time of death of 0.83 ± 0.03, in agreement with that observed _in vivo_. This comparison rests on the assumption that the ratios of ^{208}Tl to ^{212}Pb and ^{212}Pb to ^{224}Ra were the same at death as during the measurements in vivo, if not actually equal to 1.0 (allowing for branching ratios and ^{220}Rn exhalation).

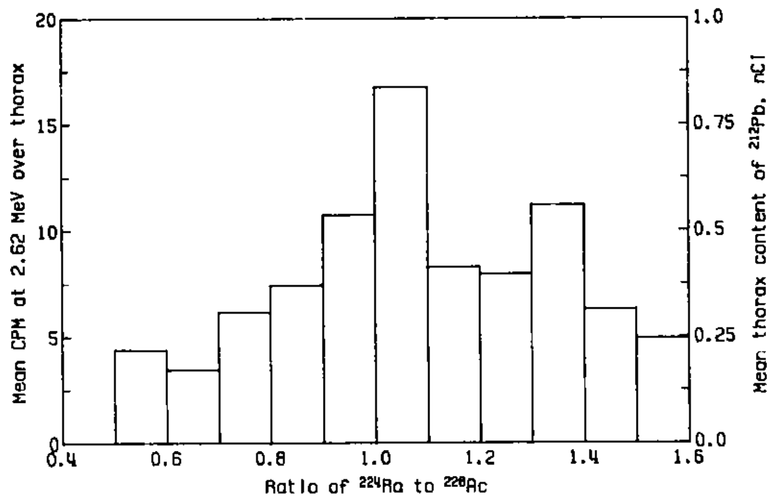

FIG. 4.-- Mean thoracic counting rates (left-hand scale) and contents of ^{212}Pb (right-hand scale) for each group of $^{224}Ra/^{228}Ac$ ratios shown in Fig. 3.

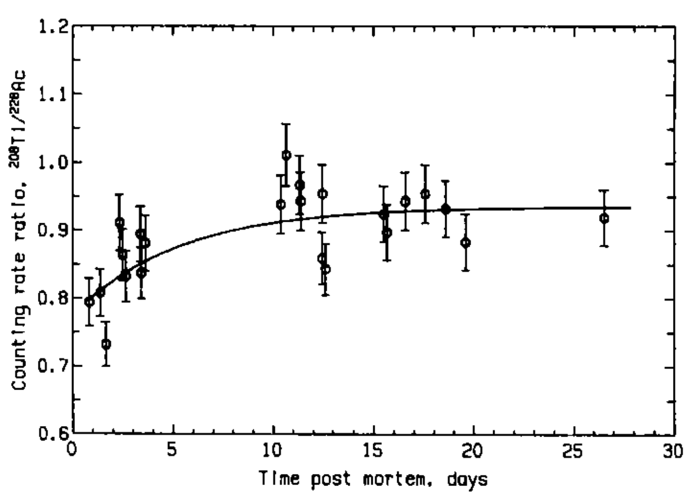

FIG. 5.-- Growth postmortem of ^{224}Ra in the lungs and thoracic lymph nodes of case L-1521, as shown by the increase in the ratio of ^{208}Tl to ^{228}Ac.

Following these measurements, the lungs and lymph nodes were placed in the simple thorax phantom and the ^{208}Tl γ rays were counted with the same procedures used in vivo. The resulting net count rate was 14.6 ± 0.6 cpm, which when corrected for the $^{224}Ra/^{228}Ac$ activity ratio of 0.83 at death equals 12.1 ± 0.7 cpm. The counting rate observed in vivo was 12.2 ± 1.3 cpm. Final validation of the calibration factors for measurements in vivo will depend on the radiochemical analyses of the lung and lymph node thorium contents, which are currently in progress.

Many difficulties are inherent in the process of analyzing thorium daughters in vivo via γ-ray spectrometry, such as low counting rates and therefore poor statistics, the effects of variations in physique among subjects, and, based on the values of the $^{224}Ra/^{228}Ac$ ratio we have observed, variability in the metabolism of thorium daughters in vivo. At this point we conclude that the value of the ratio observed is probably representative of that given individual alone; a computed mean value for a group of subjects may have little or no meaning. Nevertheless, it does appear that analyses of this parameter along with work histories, exposure records, smoking habits, and other parameters in our data base for the thorium workers will shed some light on the metabolic behavior of thorium daughters following inhalation of thorium.

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PERSONAL FACTORS AFFECTING THORON EXHALATION FROM OCCUPATIONALLY ACQUIRED THORIUM BODY BURDENS

J. H. Stebbings

Thorium workers with thorium body burdens (primarily thoracic) above 0.7 nCi ^{224}Ra equivalent are shown to exhale about 15% of thoron produced in vivo, compared to 5% exhaled by subjects with body burdens in the range of 0.4 to 0.7 nCi ^{224}Ra. There was a false negative correlation between average adult daily cigarettes smoked and thoron exhalation. White blood cell counts that were about 85% of expected were observed in seven subjects exhaling >100 pCi of thoron above predicted; no other variable examined showed a clear pattern of association. These differences in fractional thoron exhalation, and their consequences, are discussed.

Introduction

Thoron (radon-220), emanating from deposits of thorium-containing minerals in the lungs of workers engaged in thorium and rare earth refining, should intrigue the respiratory physiologist. This gas can be measured in very low concentrations in expired air, and the quantity of gas produced in vivo and retained in the body can be estimated by gamma-spectrometry of daughter products in the body. Further, because of the 55-second half-life, the number of possible physiological determinants of the fraction exhaled is fewer than in the cases either of gases with longer half-lives or gases whose rate of production is physiologically determined.

As a first approximation, one may assume that factors affecting thoron exhalation should correspond to what has been called the "membrane component" of pulmonary diffusing capacity. This is certainly an oversimplification because much of the thorium is likely to be found in the interstitium of the lung and in lymphatic tissue. Pulmonary vascular effects are likely to be of some importance, but not at all to the extent that they would be for radon-222 (half-life 3.85 days) for example. Pulmonary lymphatic circulation may be of some importance, especially as radon and thoron are much more soluble in lipids than in water.

Empirical exploration of the determinants of exhaled thoron is a first step in determining whether studies of thoron can contribute to knowledge of pulmonary physiology. We report here the initial investigations in this direction.

The results of these analyses are presented in the sequence in which the analyses were done: (1) an epidemiologic analysis of factors affecting the fraction of thoron exhaled, (2) a detailed investigation of seven subjects exhaling far more thoron than expected, and (3) an analysis of the relationship of total body thorium to fraction of thoron exhaled and to cigarette smoking. The first analyses related to the effect of smoking on thoron exhalation, and in discussions and progress reports, an impairment of thoron exhalation in cigarette smokers was postulated. This has turned out to be an oversimplification.

Methods

The data file used for these analyses was the examined thorium worker file as of August-September 1981, as developed by S. A. Conibear and I. Farid[1,2] for biochemical analyses. Specific variables used, their variable names, and definitions are shown in Table 1. Parameters of the variables are given in the Annex.

TABLE 1. Glossary of Variable Names

Variable	Definition
EMR4	Body content of emanating ^{224}Ra, pCi (referred to as "exhaled thoron").
LEMR4	$\log_e$ (EMR4).
REMR4	EMR4-4.218-117.28*THC (the residual from the observed simple regression of EMR4 on THC.).
RAT	EMR4/THC.
THC	Body content of non-emanating ^{224}Ra, nCi (referred to as "thorium body burden by gamma spectroscopy").
LTHC	$\log_e$ (THC + 1.0).
RA4	Body content of ^{224}Ra, nCi.
LRA4	$\log_e$ (RA4 + 1.0).
SMK	Smoking, [packyears/(age-20)] (average daily cigarettes smoked as an adult).
SMOKENOW	Amount of cigarettes smoked at time of examination.
MNTH	Employment duration in months.
ETOH	Alcohol consumption.
N	275 (273 for LEMR4 analyses, due to 2 zero values).

Results

<u>Relationships of Personal Characteristics to Body Burdens of Thorium.</u> Regression analyses of the relationships of components of thorium body burden (emanating, non-emanating, and total) with several personal characteristics were done first. These simple regressions related height, weight, employment duration, age at measurement, an index of cumulative alcohol consumption, and average daily cigarette consumption as an adult to thorium burdens.

The results are given in Table 2. Body weight and alcohol consumption were clearly unrelated to thorium body burdens. The data for height suggest a possible relationship, but this is not significant unless the variance of the low end of the data is inflated by log transformations. In any case, some slight negative correlation would be expected given the results of age at measurement.

TABLE 2. Simple regressions of thorium burden variables on personal characteristics of workers.

	Employment duration			Age at measurement			Weight		
	b	r^2	p	b	r^2	p	b	r^2	p
EMR4	+0.334	0.129	0.0001	+1.159	0.036	0.0017	-0.0116	0.000	0.93
LEMR4	+0.011	0.272	0.0001	+0.0470	0.110	0.0001	-0.00032	0.000	0.92
THC	+0.00291	0.341	0.0001	+0.0076	0.053	0.0001	-0.00038	0.001	0.60
LTHC	+0.00186	0.295	0.0001	+0.00478	0.044	0.0004	-0.00039	0.002	0.43
RA4	+0.00325	0.333	0.0001	+0.00877	0.056	0.0001	-0.00040	0.001	0.62
LRA4	+0.00200	0.304	0.0001	+0.00531	0.049	0.0002	-0.00038	0.002	0.47

	Height			Alcohol consumption			Smoking		
	b	r^2	p	b	r^2	p	b	r^2	p
EMR4	-1.997	0.006	0.20	-0.0044	0.002	0.44	-10.3	0.018	0.026
LEMR4	-0.0897	0.022	0.01	-0.00004	0.000	0.75	-0.463	0.069	0.0001
THC	-0.0108	0.006	0.20	-0.000003	0.000	0.92	-0.033	0.006	0.19
LTHC	-0.0109	0.013	0.06	-0.000002	0.000	0.91	-0.030	0.012	0.08
RA4	-0.0129	0.007	0.17	-0.000007	0.000	0.83	NA[a]	NA	NA
LRA4	-0.0121	0.014	0.05	-0.000004	0.000	0.85	NA	NA	NA

[a]Not Available.

Average daily adult cigarette consumption, however, does correlate negatively with exhaled thoron (EMR4).* The effect is significant for the non-transformed data, and highly significant for the transformed data. There is a suggestion of a similar relationship of thorium body burden as measured in vivo (LTHC) to smoking also. These findings suggest that cigarette smokers may retain less inhaled material and/or that smoking may interfere with emanation of thoron.

In Table 3, exhaled thoron is adjusted for body content of thorium both directly, by controlling for THC, and indirectly, by controlling for employment duration. After that adjustment, the results of smoking upon thoron exhalation are marginal (p = .07). Results are highly significant if the variance of results below 1 pCi is greatly expanded by log transformation.

At the bottom of Table 3, results indicate that any effect of smoking on thorium body burden (THC) disappears after adjustment for duration of employment.

TABLE 3. Effects of smoking upon thorium burden variables, controlling for exposure and alternative burden estimates.

Dependent variable	Controlling for	Effect of smoking		
		b	T	p
EMR4	MNTH	-7.085	-1.78	0.0768
	THC, MNTH	-6.004	-1.78	0.0724
LEMR4	MNTH	-0.3525	-4.30	0.0001
	THC, MNTH	-0.3377	-4.45	0.0001
REMR4	MNTH	-6.011	-1.81	0.0714
	THC, MNTH	-6.004	-1.80	0.0724
THC	MNTH	-0.0092	-0.49	0.62
LTHC	MNTH	-0.0147	-1.11	0.27
RA4	MNTH	-0.0159	-0.75	0.45
LRA4	MNTH	-0.0184	-1.32	0.19
RAT	MNTH	-10.07	-0.68	0.50

*See Table 1 for glossary of variable names.

The smoking effect may be better defined by references to plots. Figure 1 shows the plot of residual EMR4 values after adjustment for thorium body content and employment duration. A correlation (p = .07) exists, but clearly may be due to six outliers in the upper left. Expanding the variance of the extremely low EMR4 values, and reducing that of the high, as in Figure 2, yield a visually apparent correlation (p = .0001). Figure 3 corresponds to Figure 1, except the method of computation was different.

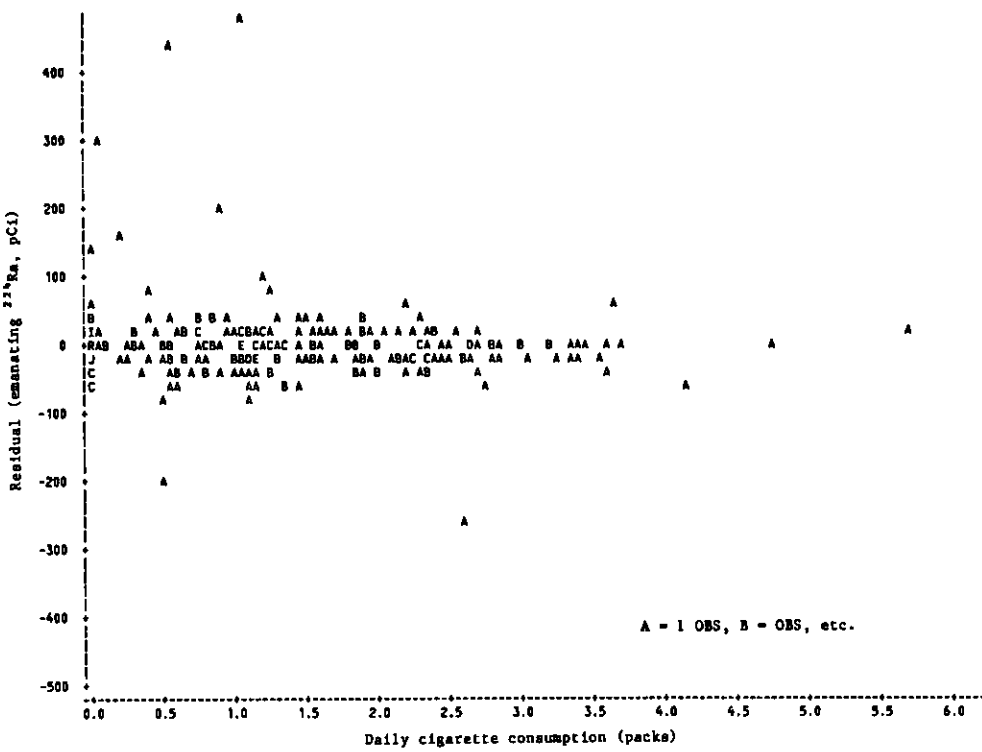

FIG. 1.--EMR4 - F(THC, Employment Duration) plotted by average adult daily cigarette consumption.

The smoking effect seems to have two components. The seven high outliers (EMR4 > 100 pCi above predicted from THC) were light or nonsmokers in adult life. As described below, six or seven subjects with high exhaled thoron were nonsmokers at time of measurement. These six outliers could induce the observed correlation for untransformed values of EMR4. For transformed values, smoking somehow discriminates between very low (1 pCi) and extremely low (< 1 pCi) values of EMR4. The interpretation of this observation is

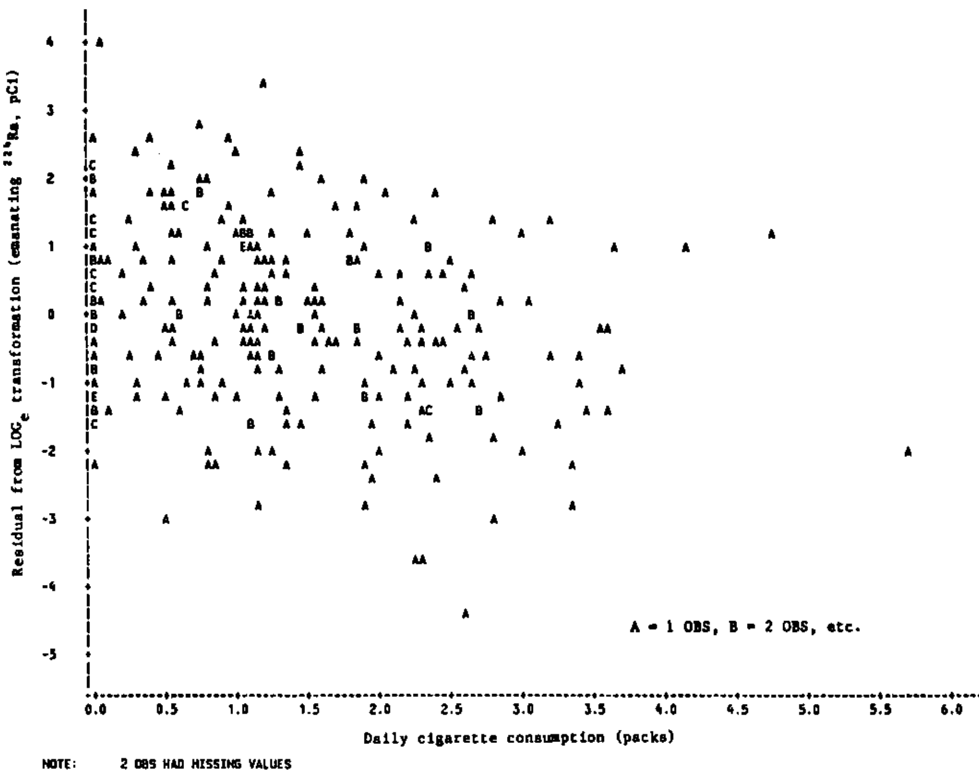

FIG. 2.--Log_eEMR4 - F(THC, Employment Duration) plotted by average adult daily cigarette comsumption.

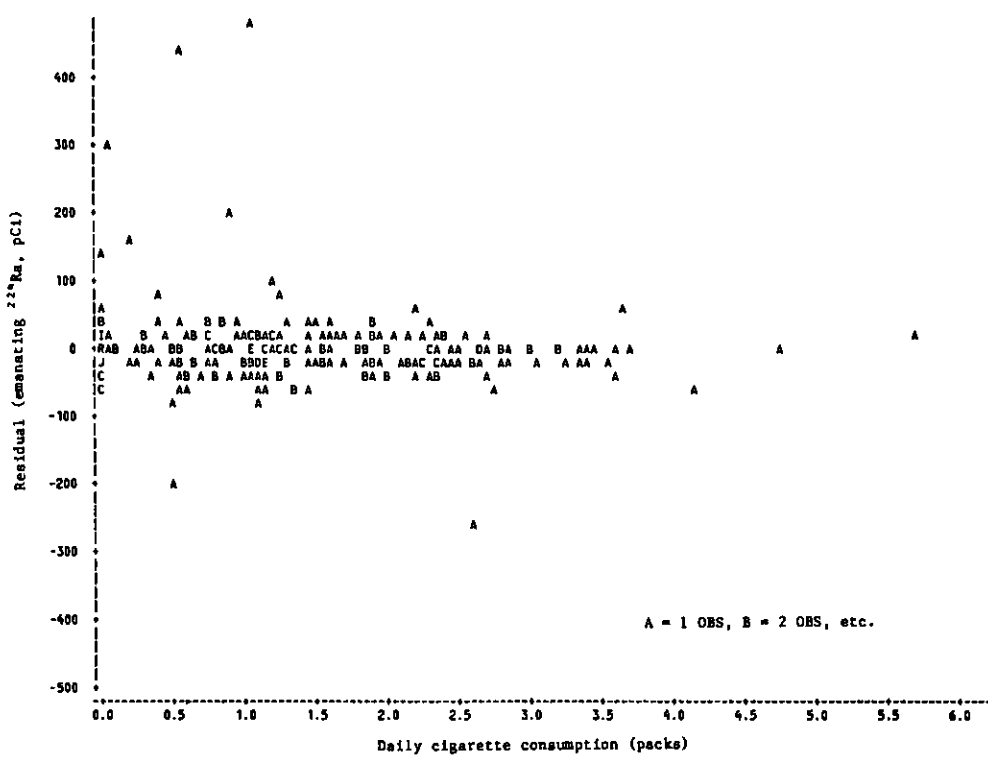

FIG. 3.--EMR4 - F(THC)) - F(Employment Duration) plotted by average adult daily cigarette consumption.

obscure. Thus, two separate factors operate to induce the smoking/exhaled thoron relationship.

The next stage of the analysis was to investigate in detail the characteristics of these seven outliers.

Characteristics of Subjects Exhaling Excessive Thoron. The seven positive outliers are described in Table 4. The outliers are positive residuals greater than 100 pCi from the regression: Exhaled thoron (pCi) = 4.218 + 117.28 * non-emanating thorium (as ^{224}Ra, in nCi). Table 4 shows the residuals and the other thorium burden parameters. No cluster of examination dates suggesting measurement artifact appears.

TABLE 4. Thorium body burden characteristics of subjects with very high thoron output for body burden.[a]

	Thoron as emanating ^{224}Ra (pCi)			Thorium as ^{224}Ra (nCi)		Examination
Case	Obs	Obs-Exp	Obs/Exp	Non-emanating	Total	date
L-0681	375	+305	5.36	0.55	0.92	1/11/79
L-1414	667	+441	2.95	1.87	1.87	7/5/79
L-1997	419	+163	1.64	2.14	2.56	5/15/79
L-2608	253	+135	2.14	0.98	1.23	7/2/79
L-2614	161	+107	2.98	0.42	0.59	8/17/76
L-3961	323	+193	2.48	1.09	1.42	4/8/80
L-4072	704	+479	3.13	1.88	2.58	10/3/79

[a]Thoron as ^{224}Ra > 100 pCi above expected given non-emanating ^{224}Ra and duration of employment.

Table 5 shows certain basic personal characteristics: age, height, weight, ethnicity, duration of employment, and yeais since work exposure. There is no suggestion that extreme values of any of these parameters determine the extremes of thoron output.

Table 6 shows cigarette and alcohol consumption in these subjects. Although adult consumption rates of cigarette smoking and alcohol consumption were about half that in the entire study population (and one expects the correlation of smoking and alcohol consumption), it is in cigarette smoking at time of examination that these subjects differ strongly from their coworkers.

TABLE 5. Work exposure and anthropometric characteristics of subjects with very high thoron output for body burden.[a]

Case	Work exposure		Personal characteristics			Spanish surname
	Duration of work (mos)	Time since work (yrs)	Age	Height (in)	Weight (lbs)	
L-0681	35	21	44	65.5	238	Yes
L-1414	50	18	46	71.0	174	No
L-1997	241	12	77	64.3	163	No
L-2608	261	6	60	70.5	185	Yes
L-2614	27	31	67	69.3	179	No
L-3961	366	8	70	65.0	169	No
L-4072	247	7	64	67.0	159	Yes

[a]Thoron as ^{224}Ra > 100 pCi above expected given non-emanating ^{224}Ra and duration of employment.

TABLE 6. Cigarette and alcohol consumption by subjects with very high thoron output.[a]

Case	Cigarettes			Alcohol consumption
	Average daily consumption (packs)	Consumption at examination (packs/day)[b]	Pack-years during employment	
L-0681	0.07	0.0	0.55	228
L-1414	0.54	0.0	0.00	248
L-1997	0.20	0.0	3.80	216
L-2608	0.00	0.0	0.00	244
L-2614	1.21	1.0	2.25	264
L-3961	0.92	0.0	30.5	0
L-4072	1.05	0.0	7.50	0
Average	0.57	0.14	6.37	171.4
Average as % of group mean[c]	44	19	110	45

[a]Thoron as ^{224}Ra > 100 pCi above expected given non-emanating ^{224}Ra and duration of employment.
[b]P = 0.0446 by Fisher's Exact Test, for prevalence of nonsmoking.
[c]Mean for 275 measured subjects

Only one of seven smoked, a statistically significant finding. This suggested that nonsmokers are likely to exhale a significantly larger fraction of thoron.

Pulmonary function values, where they existed, were reviewed on these seven subjects, but have not yet been tabulated. There was no apparent association between these extremes of thoron output and extremes of pulmonary function, although the most relevant, diffusing capacity, was often missing. Respiratory symptoms reported by six of the seven on a pre-examination questionnaire were reviewed: two reported chronic cough, one reported both chronic cough and phlegm. The latter subject, plus one other who was asymptomatic on the questionnaire, reported evidence of bronchitis on clinical examination. There is, then, no clear association between mucus hypersecretion in the lung (or its absence) and extremes of thoron output.

Hematologic parameters were investigated, since hemoglobin levels might be related to thoron-carrying capacity (assuming thoron acts similarly to xenon). Table 7 shows these results. The slight deficits in red cell parameters are

TABLE 7. Hematological characteristics of subjects with very high thoron output.[a]

Case	Hemoglobin	Hematocrit	Red blood cell count (10^3)	White blood cell count (10^3)
L-0681	16.5	48	5.58	6.0
L-1414	15.5	43	5.20	5.8
L-1997	8.9	27	3.68	5.1
L-2608	15.6	47	5.20	7.2
L-2614	14.1	48	4.80	6.0
L-3961	15.8	46	5.10	4.9
L-4072	16.0	50	5.00	8.7
Average	14.63	44.1	4.937	6.24
Average as % of group mean[b]	92	95	96 82	

[a]Thoron as ^{224}Ra > 100 pCi above expected given non-emanating ^{224}Ra and duration of employment.
[b]As percent of mean of 275 subjects (see text).

expected of nonsmokers, but the deficit in white cells is not explained by smoking status. These counts are 85% to 87% of what is expected for white male nonsmokers and ex-smokers.[3] The implications of this finding are not immediately apparent. It is important to remember that the number of atoms of thoron is very small.

In summary, we can say that a low white blood cell count is correlated with high thoron exhalation, but the nature of the relationship is obscure. Clearly, nonsmoking at time of examination is related to high thoron exhalation.

Further investigation, however, suggests that not even this relationship is causal.

Characteristics of High Thorium Burden Subjects. It was decided to investigate some characteristics of high thorium body burden subjects *per se*, without immediate reference to thoron exhalation. Subjects in the range > 0.4 nCi ^{224}Ra, clearly indicating occupational exposure, were studied.

The emanation fraction of thoron and three smoking parameters are presented: average adult daily consumption, fraction smoking at time of exam, fraction not smoking when employed. These results are shown in Table 8.

TABLE 8. Smoking and fractional thoron emanation by total thorium body burden (as ^{224}Ra, nCi).

RA4 (nCi ^{224}Ra)	Thoron fraction emanating	Cigarette smoking: Average adult consumption (packs)	Cigarette smoking: Not smoking at time of Employment	Cigarette smoking: Not smoking at time of Exam
>1.00	0.148	0.73	2/10	9/10
0.70 - 0.99	0.162	1.36	1/6	3/6
0.60 - 0.69	0.051	1.03	2/7	4/7
0.40 - 0.59	0.038	1.00	5/22	11/22

Although the fraction of nonsmokers in all groups increases, in general doubles, between time of employment and time of exam, the fraction of very high burden cases (9/10) not smoking is higher than the 50% of nonsmokers at exam in the lower burden groups. No difference during time of employment among the groups can be seen.

Whether or not statistically significant, a larger fraction of persons with the highest burdens gave up smoking after (or during) exposure, suggesting a possible causal relationship between lung burden and cessation of smoking.

It is also clear that the fraction of thoron emanating is a function of total body burden of thorium. Individuals with burdens above 0.70 nCi ^{224}Ra exhale proportionately three times the thoron exhaled by subjects with lower body burdens.

This is shown in more detail in Figure 4, which shows highly skewed distributions of fraction of thoron exhaled, with both skewness and mean increasing with increasing burden. There is also a suggestion of bimodality in the lowest burden group.

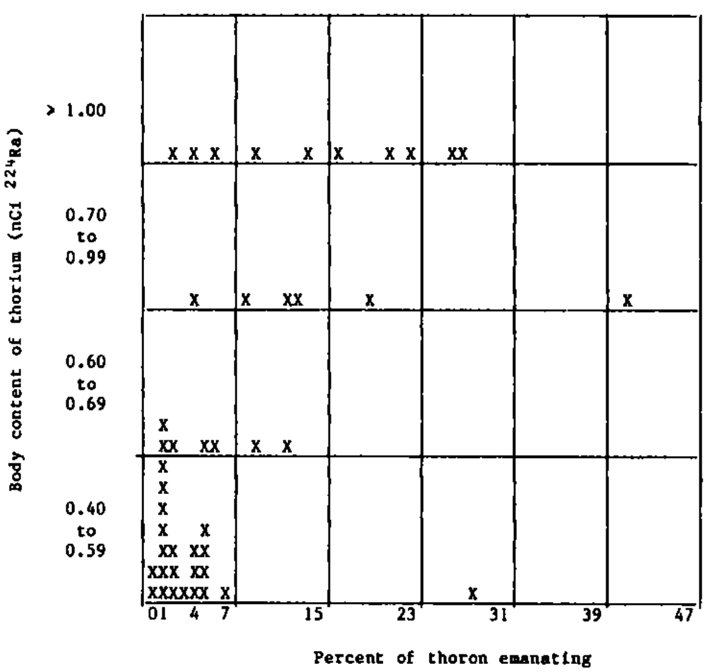

FIG. 4.--Fraction of thoron emanating by body content of thorium (expressed as nCi ^{224}Ra).

FIG. 4. Fraction of thoron emanating by body content of thorium (expressed as nCi ^{224}Ra).

Discussion

The clear finding in these analyses is that the fraction of thoron produced in the body from occupationally acquired burdens of thorium minerals that is exhaled is directly correlated with body burden. The fraction of thoron exhaled goes from 4%-5% to 14%-15% as body burdens range from 0.4-0.7 nCi (^{224}Ra) to >0.7 nCi. Bimodality at the low end suggests that even lower fractions may be exhaled at lower body burdens.

When body burden estimates are based on both exhaled thoron and gamma spectrometry measurements, this finding is of little consequence. Estimates based only on exhaled thoron in this higher dose range will generally be overestimated, up to four times, but may be underestimated, usually by not more than a factor of two.

Serious inaccuracies (tenfold underestimates) could occur if exhaled thoron were used to estimate body burdens of thorium or ^{228}Ra at population exposure levels.

There are a number of potential explanations, each lacking supportive evidence, for this phenomenon. The phenomenon may be either mineralogical or biological. That is, the mix of thorium minerals in the lungs of high burden cases may differ from that of low burden cases (whether because of exposure, uptake, or retention), and thorium decay products could be better retained in minerals in the lungs of low burden cases.

A number of biological explanations are possible: thorium-containing minerals may be distributed differently (quantitatively) in lungs of high and low burden cases; high burdens may induce pathology which leads to more rapid thoron loss; or certain biological molecules such as lipids or hemoglobin could bind thoron yet be readily saturated.

The originally observed correlation of nonsmoking with relatively high thoron output, suggestive of impaired thoron diffusing capacity in smokers, was shown to be an artifact resulting from cessation of smoking in persons with high thoracic burden of thorium (which could be due to symptoms resulting from the lung burden), combined with the high thoron output in high burden cases.

The remaining observation possibly relevant to an understanding of this phenomenon is the observation of low white cell counts in persons with very high thoron outputs.

Suggestions for Future Research

At this point, more extensive quantitative analyses of variables relating to fraction of thoron exhaled should be conducted. Further, the results of repeat measurements, when available, should be examined to determine whether exhalation fraction for thoron is relatively constant or variable in a given individual over months or years. Information on location, shape, number, and mineralogy of thorium-containing particles in lung specimens would also be useful.

References

1. S. A. Conibear, Long term health effects of thorium compounds in exposed workers: The complete blood count, Health Physics 44 (Suppl 1), 231-238 (1983).
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VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
BEGAGE	232	16.55172414	4.58936249	7.00000000	41.0000000	0.30130641	3840.0000	21.0622	27.727
AMT1	233	29.75107296	15.78395869	0.00000000	80.0000000	1.03436908	6932.0000	249.2912	53.070
YRCH1	234	73.29914530	8.12907140	36.00000000	80.0000000	0.53141402	17152.0000	66.0318	11.090
AMT2	119	11.26050420	15.66517361	0.00000000	60.0000000	1.43602411	1340.0000	245.3977	139.116
YRCH2	65	76.86153846	5.25260924	45.00000000	80.0000000	0.65150599	4996.0000	27.5899	6.834
AMT3	24	13.50000000	14.71467768	0.00000000	60.0000000	3.00362100	324.0000	216.5217	108.998
YRCH3	20	76.50000000	3.96696838	64.00000000	80.0000000	0.88704121	1530.0000	15.7368	5.186
AMT4	9	15.55555556	17.40051085	0.00000000	40.0000000	5.80017028	140.0000	302.7778	111.860
YRCH4	5	75.80000000	4.91934955	67.00000000	78.0000000	2.20000000	379.0000	24.2000	6.490
YREXAM	275	78.63636364	0.99567745	76.00000000	80.0000000	0.06004161	21625.0000	0.9914	1.266
AFTER	275	15.52363636	9.13455706	-1.00000000	40.0000000	0.55083452	4269.0000	83.4401	58.843
AGE	275	49.98909091	12.00957150	21.00000000	79.0000000	0.72420441	13747.0000	144.2298	24.024
YBSMOKE	232	45.45689655	11.67295432	19.00000000	75.0000000	0.76636703	10546.0000	136.2579	25.679
SMOKEDUR	275	65.32363636	75.22652400	0.00000000	432.0000000	4.53633008	17964.0000	5659.0299	115.160
MNTH	275	67.55272727	79.51367029	6.00000000	428.0000000	4.79515624	18577.0000	6323.2189	117.713
SMOK2DUR	275	49.18545455	68.10338700	0.00000000	372.0000000	4.10678876	13526.0000	4638.0713	138.462
YRSM1	232	27.89224138	12.62981185	0.50000000	58.0000000	0.82918777	6471.0000	159.5121	45.281
YRSM2	65	3.60769231	6.39060120	0.50000000	37.0000000	0.79265652	234.5000	40.8398	177.138
YRSM3	20	3.07500000	5.25475975	0.50000000	24.0000000	1.17500000	61.5000	27.6125	170.886
YRSM4	5	2.30000000	1.78885438	0.50000000	5.0000000	0.80000000	11.5000	3.2000	77.776
PACKYRS	275	37.29154545	33.58494777	0.00000000	180.0000000	2.02524855	10255.1750	1127.9487	90.060
WKPACKYR	275	5.76648998	9.92307107	0.00000000	89.6436486	0.59333370	1585.7847	98.4673	172.082
SMOKENOW	275	0.73127273	0.86594334	0.00000000	3.0000000	0.05221335	201.1000	0.7499	118.416
SMOKEBEF	275	21.76376271	26.26996724	0.00000000	140.2500000	1.58413863	5985.0347	690.1112	120.705
RA4	275	0.18716361	0.44699227	-0.50999999	3.4499998	0.02695465	51.4700	0.1998	238.824
YEAR	0	.	.	.	.	.	.	.	.
HHGB	275	15.93781818	1.15655335	8.90000000	18.5000000	0.06974279	4382.9000	1.3376	7.257
HHCT	275	46.50000000	3.43348687	27.00000000	54.0000000	0.20704705	12787.5000	11.7888	7.384
HRBC	275	5.12236364	0.39978992	3.68000000	6.2000000	0.02410824	1408.6500	0.1598	7.805
HWBC	275	76.32000000	24.25802900	25.00000000	220.0000000	1.46281419	20988.0000	588.4520	31.785
HEOS	275	2.10545455	1.96496858	-1.00000000	11.0000000	0.11849206	579.0000	3.8611	93.328
HBFL	275	-0.21454545	0.98592618	-1.00000000	3.0000000	0.05945359	-59.0000	0.9721	-459.542
HSTB	275	1.79272727	2.23703520	-1.00000000	13.0000000	0.13489830	493.0000	5.0043	124.784
HMNC	275	5.85090909	2.93785218	-1.00000000	18.0000000	0.17715915	1609.0000	8.6310	50.212
HTLP	275	30.13454545	7.74314432	13.00000000	57.0000000	0.46692917	8287.0000	59.9563	25.695
HFMN	275	59.44000000	8.45031853	36.00000000	79.0000000	0.50957338	16346.0000	71.4079	14.217
HABEOS	275	163.79272727	141.61368219	0.00000000	756.0000000	8.53962635	45043.0000	20054.4350	86.459
HABBFL	275	23.61090909	47.43298643	0.00000000	231.0000000	2.86031670	6493.0000	2249.8832	200.894
HABSTB	275	154.36000000	172.85679656	0.00000000	972.0000000	10.42365703	42449.0000	29879.4721	111.983
HABMNC	275	438.26909091	253.67137837	0.00000000	1870.0000000	15.29695967	120524.0000	64349.1682	57.880
HABL	275	2269.10181818	871.73210232	765.00000000	7392.0000000	52.56742366	624003.0000	759916.8532	38.417
HABP	275	4578.36000000	1788.90949468	1075.00000000	16940.0000000	107.87530141	1259049.0000	3200197.1801	39.073
AGEGRP	275	2.51636364	1.10188353	1.00000000	4.0000000	0.06644608	692.0000	1.2141	43.789
RA4GRP	275	1.81454545	0.68226174	1.00000000	4.0000000	0.04114193	499.0000	0.4655	37.600
PKYRGRP	275	2.51272727	1.12487705	1.00000000	4.0000000	0.06783264	691.0000	1.2653	44.767
EMR4	275	23.47272579	74.02201938	0.00000000	704.0000000	4.46369572	6454.9996	5479.2594	315.353
THC	275	0.16392725	0.39691578	-0.51999998	3.3299999	0.02393492	45.0800	0.1575	242.129
RAT	263	15.94831583	247.04143071	-2585.99907464	681.8182409	15.23322720	4194.4071	61029.4685	1549.013
LEMR4	273	1.57901251	1.70353114	-2.30258545	6.5567784	0.10310542	431.0704	2.9022	107.889
LTHC	275	0.11056298	0.27237516	-0.73396914	1.4655675	0.01642434	30.4048	0.0742	246.353
LRA4	275	0.12410104	0.28337760	-0.71334987	1.4929041	0.01738982	34.1278	0.0832	232.373
SMK	275	1.30553022	1.05139831	0.00000000	5.7222222	0.06340110	359.0208	1.1054	80.533
REMR4	275	0.02999524	57.55349065	-268.75350376	479.2997325	3.47060607	8.2487	3312.4943	99999.000
LRAT	261	1.36807605	37.72576902	-325.26974855	153.9235459	2.33516648	357.0678	1423.2336	2757.578
WT	275	178.54080000	32.86632152	109.34000000	316.5800000	1.98194391	49098.7200	1080.2280	18.409
HT	275	68.39909520	2.84472613	60.51181102	75.0000000	0.17154344	18809.7512	8.0925	4.159
ETOH	275	378.37818182	790.31328600	0.00000000	5184.0000000	47.65768430	104054.0000	624595.0900	208.869

MEASUREMENT OF LYMPHOBLASTOGENIC ACTIVITY FROM THORIUM WORKERS*

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Mitogenic stimulation of peripheral blood lymphocyte cultures obtained from 36 thorium workers was studied to determine whether the response of these cells was affected by the individuals' occupational exposure to alpha irradiation. The standard assay involved incubating 2 x 10^5 lymphocytes per test well for 72 hours in the presence of phytohemagglutinin (PHA), concanavalin A (Con A) or pokeweed mitogen (PWM). The results showed that there was a significant decrease in lymphocyte responsiveness of former thorium workers grouped by decade of life when compared with controls of the same decade of life for each mitogen tested with the exceptions of PHA in the 41-50 age group and PWM in the 51-60 age group. We are unable to correlate the decreased response observed with the measured body burdens, external gamma exposure, or thoron exhalation rates in these thorium cases. However, other occupational exposures (i.e., various chemicals used in processing thorium) cannot be eliminated as a possible cause.

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ARGONNE-UTAH STUDIES OF ^{224}Ra ENDOSTEAL SURFACE DOSIMETRY*

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The activities of ^{212}Pb relative to ^{224}Ra and of ^{222}Rn relative to ^{226}Ra were measured in bone surface deposits 24 h after injection of radium into beagles. The fractional retention of ^{220}Rn atoms was measured in vitro with hydrated and dehydrated bone samples to determine the effect of water content on the escape of radon from bone surfaces. The experimental data suggest that substantial ^{224}Ra daughter-product disequilibrium exists in bone surface deposits. Estimates for the lower and upper limits on the fractional retention of ^{220}Rn in vivo are 0.05 and 0.25, respectively. The average bone surface activity of ^{212}Pb relative to ^{224}Ra ranged from 0.34 to 0.71 for four dogs, with the majority of the values toward the lower end of the range. Only a small portion of the deposited ^{212}Pb came from lead in the injection solution despite near equilibrium between ^{224}Ra and its daughters at the time of injection. The retention data indicate that the endosteal tissue dose rate in the dogs at one day was actually one-third to about one-half that which would be calculated assuming equilibrium of ^{224}Ra daughter products in bone surface deposits.

Introduction

German patients injected with ^{224}Ra to alleviate the pain of certain diseases of the skeleton[1,2] provide one of the best sources of information on the risk of cancer in humans from internal emitter exposure. Although doses to bone have been calculated with the assumption that ^{224}Ra daughter products are completely retained,[3] three retention studies conclude or imply the opposite.[4-6] We have focused on this question with an experiment designed to examine the state of equilibrium between ^{224}Ra and two of its daughters, ^{220}Rn and ^{212}Pb, at the endosteal surfaces of dog bone.

Materials and Methods

Six beagles, 19 to 25 months of age, were selected from the colony at the

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University of Utah. Four were injected with ^{224}Ra nearly in equilibrium with its daughter products; one was injected with ^{226}Ra separated from its daughters; and the sixth was injected with ^{212}Pb. All were sacrificed 24 h after injection. Information on sex, weight, injection level, and age is given in Table 1. The dog identification numbers are slightly modified from those found in the tabular data on experimental dogs listed annually in the University of Utah progress report under the heading "Test Animals".[7]

TABLE 1. Data on experimental animals.

Dog No.	Sex	Age, days	Weight, kg	Nuclide	Activity injected, μCi
T28Q5	M	577	10.9	^{224}Ra	91.8
T29Q5	M	593	13.0	^{224}Ra	95.3
T30Q5	M	606	12.1	^{224}Ra	119
T31Q5	F	775	10.5	^{224}Ra	111
T115R5	M	572	11.4	^{226}Ra	99.6
T21L5	F	605	7.2	^{212}Pb	106

Long bones were defleshed, the mid-diaphyses excised and cut longitudinally, and the marrow was removed, usually with a pressurized stream of n-butyl alcohol. Samples were transported to Argonne by airplane, and the endosteal surface activity was measured in vacuum by alpha spectrometry in a way similar to that previously described[8] but without collimation. In some cases, marrow removal was delayed until the samples arrived at Argonne.

Alpha spectra similar to those shown in Figure 1 were obtained from all samples measured in vacuum except in cases of equipment failure. The spectrum peaks correspond to alpha particle emissions from bone surface deposits and the tails correspond to emissions from volume deposits. In some cases, the spectra of individual radionuclides were separated from the total by stripping techniques. In all cases, the heights of peak maxima above the substructure from higher energy alphas were measured. To obtain experimental data on the retention of ^{220}Rn, ^{212}Bi, and ^{212}Po in the dogs injected with ^{224}Ra and the retention of ^{214}Po in the dog injected with ^{226}Ra, we derived ratios of daughter product to parent activity from integrals of the peaks in stripped spectra or from the peak heights.

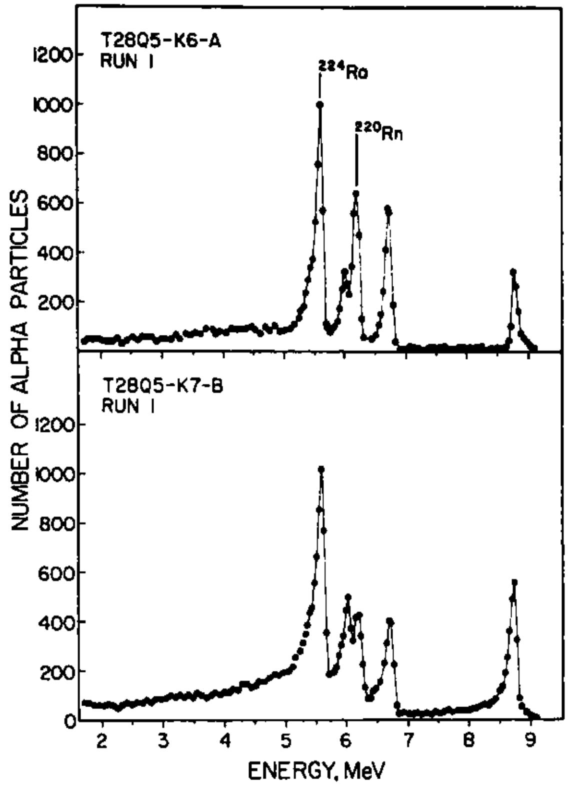

FIG. 1.-- Alpha particle spectra emitted from the endosteal surfaces of mid-diaphysis bone samples from the right (T28Q5-K6-A) and left (T28Q5-K7-B) tibiae of dog T28Q5. Starting at the left, the peaks correspond to ^{224}Ra, ^{212}Bi, ^{220}Rn, ^{216}Po, and ^{212}Po.

Bone sample surface areas measured from photographs taken from the vantage point of the detector were used to normalize peak counting rates for the intercomparison of bone surface uptake in different dogs. The areas obtained were systematic underestimates, probably by about 5% to 15%, of the true three-dimensional surface areas. Although these underestimates affected the normalized counting rate, the error was not large enough to invalidate the comparison. The values obtained, however, were especially useful for interpretation of the data from the dog injected with ^{212}Pb.

Radon Retention

^{220}Rn Retention in Vacuum. Fractional retention data are presented in Table 2. Since the half-life of ^{220}Rn is only 55 s, the data do not reflect the retention *in vivo* but can be used to establish an upper limit for it.

When hydrated bone samples containing ^{226}Ra are placed in vacuum, they dry rapidly, and ^{222}Rn retention increases abruptly. The classic buildup of radioactivity in Figure 2, observed by alpha spectrometry of the cortical endosteal surface of a bone piece from the University of Utah collection, is consistent with a near instantaneous increase in ^{222}Rn retention coincident with the start of measurement in vacuum. Although not demonstrated here, rehydration of the vacuum-dried bone by exposure to an atmosphere saturated with water vapor reduces the ^{222}Rn retention substantially.

TABLE 2. Fractional retention of ^{220}Rn in vacuum during the initial 4000 s of observation.

Dog No.	No. samples	$^{220}Rn/^{224}Ra$ Average	Range
T28Q5	7	0.58	0.41-0.72
T29Q5	8	0.76	0.65-0.91
T30Q5	8	0.58	0.41-0.70
T31Q5	8	0.64	0.55-0.69

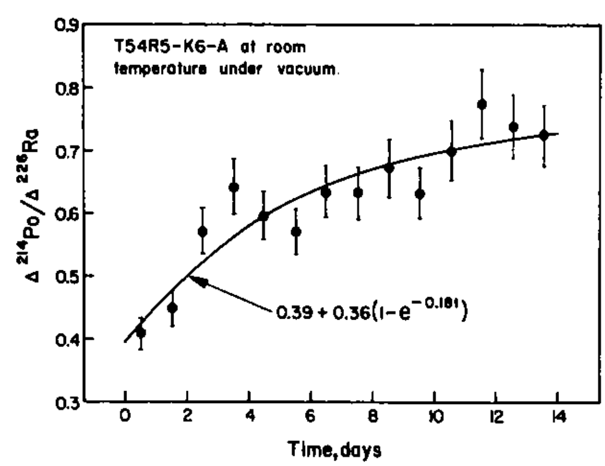

FIG. 2.-- Buildup of ^{214}Po activity in a bone sample from the right tibia of a dog injected with ^{226}Ra, as a function of time in vacuum. Prior to evacuation, the sample was in radioactive equilibrium. The ordinate is proportional to the ratio of ^{222}Rn and ^{226}Ra activities. The curve fit to the data is based on the decay constant of ^{222}Rn, 0.181 day^{-1}. Data were collected by alpha spectrometry of the endosteal surface.

The chemical identity of ^{220}Rn and ^{222}Rn guarantees that the same qualitative behavior occurs for fractional ^{220}Rn retention during dehydration under vacuum, but the change is so abrupt and the ^{220}Rn half-life so short that the change cannot be observed with the normal counting intervals of 4000 s or more.

It, therefore, seems certain that ^{220}Rn retention at bone surfaces in the fluid-saturated state that exists _in vivo_ would be no greater than the values given in Table 1; despite its short half-life, ^{220}Rn generated by bone surface deposits of ^{224}Ra _in vivo_ is not in equilibrium with ^{224}Ra.

^{222}Rn Retention at Bone Surfaces In Vivo. The ratio of ^{222}Rn to ^{226}Ra activities, based on observations of surface- deposited ^{214}Po and ^{226}Ra in seven bone samples from dog T115R5, is shown in Table 3. Because the half-life of ^{222}Rn is 3.83 days and measurement began within 9 h of sacrifice, the data strongly reflect the retention in vivo during the 24 h between injection and death. By lengthy analyses, the data can be shown to be consistent with a constant fractional retention of the ^{222}Rn atoms produced in vivo of between 0.05 and 0.10 during the survival period. Due to the chemical identity of the two isotopes, it is not likely that ^{220}Rn retention would be less than ^{222}Rn retention. Therefore, the ^{222}Rn data set a lower limit to the fractional retention of ^{220}Rn in vivo.

TABLE 3. Ratio of ^{222}Rn to ^{226}Ra surface activities during the first 20000 s of measurement.

Sample No.	$^{222}Rn/^{226}Ra$
1	0.030
2	0.027
4	0.035
5	0.030
6	0.026
7	0.027
8	0.029
Average	0.029
Standard deviation	0.003

Effect of Water. During the course of these studies, it became clear that surface water content was a major controlling factor in determining surface retention of ^{220}Rn. This factor was demonstrated indirectly by studies of ^{222}Rn retention, such as shown in Figure 2, and directly by observations of dramatic decreases in ^{220}Rn retention when surface moisture was added to vacuum-dehydrated samples from dog T31Q5. The results of one series of experiments in which samples were placed at room temperature in a chamber containing 100% relative humidity are reported in Table 4. The samples were in the chamber long enough to establish radioactive equilibrium between ^{212}Pb and retained ^{220}Rn. This equilibrium allowed measurement of ^{220}Rn retention in the water-vapor-saturated atmosphere to be based on observation of ^{212}Pb daughters by alpha spectrometry in vacuum. Fractional retention during storage in the vapor-saturated atmosphere was only one-fifth that observed in vacuum following storage (0.19 vs. 0.95). Other samples under similar conditions of storage gave average fractional retentions in the range 0.20-0.30.

TABLE 4. Fractional ^{220}Rn retention for bone samples stored in a water-vapor-saturated atmosphere and in vacuum after storage.

Sample No.	Vapor	Vacuum
1	0.15	0.88
2	0.12	1
3	0.10	0.93
4	0.23	1
5	0.22	0.88
6	0.26	0.94
7	0.21	0.96
8	0.23	1
Average	0.19	0.95
Standard deviation	0.06	0.05

The moisture level of bone bathed in body fluid is higher than that in a vapor-saturated atmosphere as judged by differences between bone sample weights after water soaking and exposure to vapor. Therefore, the fractional retention in vivo should be at least as low as in the vapor chamber and might be lower if an additional reduction accompanies additional water. The upper limit to fractional ^{220}Rn retention in vivo therefore appears to be about 0.25.

Rate of Diffusion. The surface deposit of radium in dog bone is almost certainly less than 3-μm thick.[9] The time required for a diffusing radon gas atom to travel this distance by random walk is 0.2 s, assuming a diffusion coefficient of 2.2×10^{-7} cm^2/s,[10] identical to that for photographic emulsion, which, like bone, is a composite of inorganic crystals and organic matrix. This time is less than 1/250 of the half-life of ^{220}Rn. By this argument, nearly all ^{220}Rn atoms not trapped in bone crystals[11] should escape the surface deposit, and the difference in retentions between ^{220}Rn and ^{222}Rn should be negligible.

When fresh bone samples are measured in vacuum for many half-lives, the fractional retentions of ^{220}Rn and ^{222}Rn approach asymptotic values, which differ substantially from one another--about 0.30 for ^{222}Rn and about 0.75 for ^{220}Rn--contrary to the above prediction. The conditions of measurement, the surface deposit thicknesses,[9] and the mechanisms of retention and transport are essentially identical for both isotopes. The only difference is in the half-lives. Therefore, at the low moisture content in vacuum, the actual rate of diffusion is apparently much slower than implied by the diffusion coefficient previously assumed. Though perhaps coincidental, the ratio of fractional retentions after prolonged measurement in vacuum (0.75/0.30 = 2.5) is about the same as the ratio of the fractional retention of ^{220}Rn in water-vapor-saturated bone to the fractional retention of ^{222}Rn in vivo (≅ 0.25/0.1 = 2.5). This similarity in values may mean that diffusion is also slow in fully hydrated bone, although such a conclusion would be speculative since vapor-saturated bone is not fully hydrated.

From this and preceding sections, we conclude that fractional ^{220}Rn retention at bone surfaces in vivo is 1 to 2.5 times that for ^{222}Rn and lies somewhere in the range of about 0.05 to 0.25.

^{212}Pb Retention

The retention of ^{212}Pb is determined from the combined alpha activities of its daughters, ^{212}Bi and ^{212}Po, with the aid of the Bateman equations. The calculation depends on the ^{220}Rn retention during the time between death and first measurement, a period of 8.7 to 11.1 h for the ^{224}Ra-injected dogs. During most of this time, the samples were sealed in plastic bags. The fractional ^{220}Rn retention for bagged samples was estimated to be 0.27 from observations on bone from dog T31Q5 prepared, packaged, and shipped under the same conditions as most other samples.

The retention of ^{212}Pb in vivo, expressed as the ratio of ^{212}Pb activity to ^{224}Ra activity at death, is presented in Table 5. The values for dog T28Q5 are substantially higher than the values for the other dogs. We do not believe that this is an artifact but have no explanation for it other than biological variability.

TABLE 5. Ratio of ^{212}Pb to ^{224}Ra surface activities at death.

Dog No.	$^{212}Pb/^{224}Ra$	
	Average	Range
T28Q5	0.71	0.41-1.3
T29Q5	0.34	0.26-0.40
T30Q5	0.40	0.31-0.48
T31Q5	0.36	0.28-0.43

Lead activity on bone surfaces in the ^{224}Ra-injected dogs comes from two sources: the decay of ^{224}Ra and its daughters and the uptake of ^{212}Pb contained in the injected solution. The relative amounts of ^{212}Pb activity at death normalized to the projected bone surface area and to the injected activity of ^{212}Pb are given in Table 6 for three ^{224}Ra-injected dogs and for the ^{212}Pb-injected dog. The result for the ^{212}Pb-injected dog is much lower than for any of the ^{224}Ra-injected dogs, clearly implying that 24 h after injection, little bone surface ^{212}Pb comes from the injection solution. Therefore, injected ^{212}Pb has little influence on the endosteal dose rate one day after injection.

TABLE 6. Concentrations of ^{212}Pb activity on bone surfaces at death normalized to the activity of ^{212}Pb in the injection solution.

Dog No.	Relative value, cm^{-2}
T28Q5	1.1 ± 0.3
T29Q5	0.5 ± 0.1
T30Q5	0.6 ± 0.1
T21L5	0.1 ± 0.07

Energy Release

The fractional reduction in the endosteal dose rate from surface deposits caused by the disequilibrium of ^{224}Ra daughter products at bone surfaces can be estimated by comparing the average alpha particle energy released per ^{224}Ra disintegration under the different retention assumptions. Values are given in Table 7 for the four ^{224}Ra-injected dogs under the assumptions that ^{212}Bi and ^{212}Po are in equilibrium with ^{212}Pb and fractional ^{220}Rn retentions are 0.05 and 0.25. For comparison, the average energy released is 27.6 MeV under the assumption of decay series equilibrium and is 26.5 MeV under the assumption of complete retention with no deposition of injected daughters. Therefore, the actual endosteal dose rate at 24 h is about one-third to one-half of the equilibrium dose rate, depending on the dog.

TABLE 7. Average alpha energy (MeV) released per ^{224}Ra disintegration under different ^{220}Rn retention assumptions.

Dog No.	$^{220}Rn/^{224}Ra$ 0.05	0.25
T28Q5	11.8	14.5
T29Q5	8.9	11.5
T30Q5	9.2	11.8
T31Q5	9.1	11.7

Applicability to Human Dosimetry

Because ^{220}Rn is chemically inert, species differences in retention are not likely to arise from differences in body chemistry. Thicknesses of radionuclide deposits on bone surfaces are the same in humans and dogs.[9] Therefore, the distance that a ^{220}Rn atom must travel to escape from the deposit is the same in both species. Differences in retention could arise from differences in the rate of diffusion. It should be possible to judge whether this occurs by conducting studies of ^{220}Rn retention following bone-surface deposition *in vitro*.

Lead-212 is a chemically reactive metal and there is no reason to believe that ^{212}Pb retention would be the same in humans and dogs. The retention in humans might be estimated by extrapolation of ^{212}Pb retention from the species in which it has been measured.

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RETENTION OF PLUTONIUM IN THE BEAGLE AFTER GASTROINTESTINAL ABSORPTION*

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A 0.01 M bicarbonate solution containing 130 nCi (~5 kBq) of ^{237}Pu (90% hexavalent, 93% ultrafilterable) was administered via gelatin capsule to six adult male beagles following a 21-hr fast. The dogs were sacrificed after 5-6 weeks and the percentage of the administered plutonium retained in the liver plus skeleton and its distribution within the skeleton were determined. The mean amount retained in these tissues was (0.063 ± 0.006)% of the administered dose. The mean amounts of plutonium in the liver and the skeleton were approximately equal, and the distribution within the skeleton was similar to that observed by other workers following either intravenous injection or inhalation. Our value for plutonium retention by the dog is about a factor of three less than the values we have reported for rodents. It is a factor of 7 greater than the product of the values for gastrointestinal absorption (f_1) and fractional retention (f_2) recommended by the ICRP for man.

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PLUTONIUM METABOLISM IN THE BABOON AND THE DOG - COMPARISON OF THE BEHAVIORS OF ABSORBED AND INJECTED ISOTOPES AND DETERMINATION OF GASTROINTESTINAL ABSORPTION

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Two isotopes of plutonium were administered simultaneously to a baboon and two to a dog, one intragastrically and one intravenously. Samples of urine, blood, and tissues were taken and analyzed. The results indicate that the metabolism of absorbed plutonium is the same as that of injected plutonium. They also show that the value for the fractional absorption of plutonium from the GI tract can be calculated from the amounts of the isotopes administered and the value of the ratio of their concentrations in a single sample of urine, blood, or tissue.

In a previous experiment, two isotopes each of plutonium, uranium, and neptunium were administered concurrently to a baboon — one isotope of each intravenously (I.V.) and one intragastrically (I.G.). A third isotope of plutonium was administered intragastrically at another time. Data on the excretion and retention of the plutonium isotopes that were administered concurrently have been reported.[1] The fraction of the I.V. plutonium that was excreted was 0.11 and the fraction of the absorbed I.G. plutonium that was excreted was 0.80. The fraction of I.G. plutonium retained in liver and bone was 1.3×10^{-4}, and the fraction excreted in urine was 8×10^{-4}. It was therefore concluded that the metabolism of absorbed plutonium was very different from that of injected plutonium.

It now appears that the bulk of the I.G. plutonium in urine was due to contamination from feces, not plutonium that had been absorbed from the gut and excreted. The first evidence for this was the difference between the urinary excretion patterns of the two I.G. isotopes, ^{236}Pu and ^{239}Pu. The administration of ^{236}Pu was concurrent with the I.V. administration of ^{238}Pu. The ^{239}Pu was administered two weeks prior to the ^{236}Pu

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administration; its fractional retention in tissues was essentially the same as that of ^{236}Pu. On days 2, 4, 5 and 7 the values of the ratio of the amount of ^{236}Pu in that day's urine to the amount retained in tissues on day 32 were 1.2, 1.0, 0.36, and 0.12, respectively, and for ^{239}Pu the values were 0.013, 0.71, 0.48 and 0.13. A possible explanation for these values was that all the urines in the ^{236}Pu experiment were contaminated, and in the ^{239}Pu experiment the day 2 urine was not contaminated while those on day 4 (or day 3) and every day thereafter were. Supporting this explanation was the observation that ^{239}Np, a gamma-emitting nuclide that was administered with ^{239}Pu, did not appear in the feces until day 3.

Preliminary results from an experiment with another baboon strongly supported this explanation. On day 4 a urine sample was obtained by catheterization, and that sample and the 24-hr urine sample were analyzed. The values of the activity ratios (I.G. to I.V.) in these samples were 0.62 and 7.0, respectively.

It should be noted that the problem of fecal contamination was very probably the consequence of the physiology and/or behavioral habits of the baboon, not poor practice on the part of the scientist. Particular care was exercised to prevent fecal contamination, including a change of cage in the experiment with the second baboon. Fecal contamination occurred in all three experiments; every urine sample from the experiments with the first baboon was contaminated except the day 1 sample in the ^{236}Pu experiment and the day 2 (or day 1) sample in the ^{239}Pu experiment. In each of the experiments, the degree of contamination on a particular day was about the same.

A reassessment of the data obtained in the first baboon experiment, the one in which there were concurrent intragastric and intravenous administrations, indicated that the metabolism of the absorbed isotope may have been the same as that of the injected isotope. The value of the ^{236}Pu to ^{238}Pu activity ratio in bone, 0.021 ± 0.002, was nearly the same as that in liver, 0.024 ± 0.001, and these values agreed with the value for the blood sample obtained at 4 h, 0.023 ± 0.005. The value of the ratio in the day 1 urine sample, the only one that might not have been contaminated, was 0.030 ± 0.001.

In view of the agreement among the values of the activity ratio in the baboon, a comparable but more detailed experiment was performed in a dog. The choice of a dog, rather than another baboon, was based on its immediate availability and recognition of the fact that a number of both blood and catheterized urine samples could be taken easily (without tranquilization) and that these samples would very probaby be free of contamination. The dog was an adult male beagle that had been fasted for 19 h. Two isotopes were administered concurrently: ^{239}Pu intragastrically (by gelatine capsule) and ^{236}Pu intravenously. The oxidation state of the plutonium was VI in both cases; the medium was 0.01 M $NaHCO_3$ containing 1 ppm chlorine, and the amounts were 5.0×10^5 and 7.4×10^2 pCi, respectively. Urine samples were obtained by catheterization on days 1, 2, and 6, and blood samples were obtained on days 0.2 (5 h), 1, 2, and 3. The dog was sacrificed on day 15 and two samples of bone (thoracic and cervical vertebrae) and two of liver were taken. These samples were analyzed by alpha spectrometric isotope dilution using ^{242}Pu as the diluent. The results obtained in the analyses of the urine, blood, and tissue samples are presented in Table 1.

The metabolic equivalence of the absorbed and injected isotopes is demonstrated by (1) the agreement among the values of the activity ratios in blood, (2) the agreement between the systemic values and those in urine and (3) the agreement among the tissue values. If the behaviors of the two isotopes were not the same, one would expect (1) a change in the value of the ratio in blood when the concentration in blood was decreasing by a factor of 15, (2) a difference between the values of the ratio in urine when the primary systemic source was blood (day 1) and when it was tissues (day 6), and/or (3) the ratio of the fractional retentions of the isotopes in liver to be different from the ratio of these values in bone.

The agreement of all the values of the activity ratio, and particularly those for bone and liver, suggests strongly that the value of the ratio for all the systemically retained plutonium is the same as that in any one tissue. With this being so, the value of the activity ratio in bone (or liver) is equal to the amount of the I.G. isotope that was absorbed and retained in all tissues divided by the amount of the I.V. isotope that was retained in all tissues. Thus, the fractional retention of I.G. plutonium could be calculated. The amounts of the plutonium administered I.V. and I.G. were known, the degree of retention of I.V. plutonium in the beagle dog had been determined previously,[2] and the value of the activity ratio in tissues was measured. Using the value of the activity ratio in bone, the value obtained for fractional retention of the I.G. isotope was 6.8×10^{-4}. In an earlier experiment we obtained a value of 6.3×10^{-4} for fractional retention in bone and liver.[3] An estimate of the fractional retention of plutonium in all the tissues of these dogs is 10.2×10^{-4}. The fractional retention of intravenously injected plutonium in the liver of the dog is 0.31,[2] and the ratio of the amount of plutonium in the liver to the amount in the skeleton is 1.00.[3]

TABLE 1. Relative concentrations (activity ratios) of ^{239}Pu and ^{236}Pu in samples of blood, urine, bone and liver of a dog following their concurrent administrations, ^{239}Pu intragastrically and ^{236}Pu intravenously.

Sample	Day	$^{239}Pu/^{236}Pu$ activity ratios[a]
Blood	0.2	0.59 ± 0.01 (1.00)
	1	0.55 ± 0.03 (0.26)
	2	0.55 ± 0.04 (0.14)
	3	0.54 ± 0.05 (0.07)
Urine	1	0.57 ± 0.07 (1.00)
	2	0.59 ± 0.07 (0.07)
	6	0.60 ± 0.2 (0.08)
Liver	15	
Left lobe		0.43 ± 0.02
Right lobe		0.48 ± 0.02
Bone	15	
Thoracic vert.		0.51 ± 0.02
Cervical vert.		0.52 ± 0.03

[a] Values in parentheses are relative concentrations of ^{239}Pu in each sample category.

Having demonstrated that the metabolic behaviors of absorbed and injected plutonium in the dog were the same, we calculated the fractional retention of absorbed plutonium in the baboon. The amounts of the isotopes administered were known, the amount of the I.V. isotope excreted in urine had been measured and hence the fractional retention of the I.V. isotope was known, and the values of the activity ratios in various tissues had been determined. Based on the values for blood, bone, and liver, the calculated values for the fractional retention of I.G. plutonium are $(2.2 \pm 0.5) \times 10^{-4}$, $(2.0 \pm 0.1) \times 10^{-4}$ and $(2.3 \pm 0.1) \times 10^{-4}$, respectively. The measured value, the sum of the amounts found in bone and liver divided by the amount administered, was $(1.3 \pm 0.1) \times 10^{-4}$. The difference between the calculated and measured values is undoubtedly the consequence of plutonium being present in tissues other than bone and liver.

The conclusion that can be drawn from the results of these experiments is that the fractional retention of intragastrically administered plutonium can be determined by concurrently administering known amounts of two isotopes, one intragastrically and one intravenously, obtaining any one of three types of samples, and analyzing the sample to establish the ratio of the amounts of the administered isotopes in the entire animal. The samples may be blood taken at least 5 hours after the administrations, urine taken by catheterization on day 1 or later, or tissue (bone or liver) obtained after a number of days, either by biopsy or at sacrifice.

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PROBLEMS AND PRECISION OF THE ALPHA SCINTILLATION RADON COUNTING SYSTEM

H. F. Lucas and F. Markun

Variations in efficiency as large as 3% have been found for radon scintillation counting systems in which the photomultiplier tubes are sensitive to the thermoluminescent photons emitted by the scintillator after exposure to light or for which the resolution has deteriorated. The additional standard deviation caused by counting a radon chamber on multiple counting systems has been evaluated and the effect, if present, did not exceed about 0.1%. The chambers have been calibrated for the measurement of radon in air, and the standard deviation was equal to statistical counting error combined with a systematic error of 1.1%.

Introduction

Our alpha scintillation radon counters were not routinely producing results within the expected statistical limits of counting error plus about 1%. In an earlier effort[1], several improvements in the calibration and setup of the system were instituted. However, an average error of about 2-3% was still found in addition to that due to counting statistics. Recent studies have identified two problems with the photomultiplier tubes. After correction of these problems, the variance introduced by the different counting systems was evaluated. The results of that evaluation, as well as discussion of the precision achieved when calibrating the alpha scintillation counters for the measurement of radon in air, are presented in this report.

Thermoluminesence

Thermoluminesence (TL) is the release, in the form of visible light, of energy absorbed from a previous irradiation. For a TL type of crystalline material, a portion of the absorbed energy is presumed to be stored in a defect or an impurity site.[2] When the crystal is heated, sufficient energy is given to a trapped electron that it recombines with a hole and a TL photon is emitted. The energy gap, E, is related to the temperature needed to release the electron. For most TL materials, there are a number of trap levels.

When the energy of the trap, E, is less than ~0.8 eV, many electrons are released at room temperature and the common phosphoresence is observed. Thus TL is a retarded or "frozen-in" phosphoresence that is released upon heating. The release of this stored energy is exponential with time, the half-life decreasing with an increase in temperature.

When the scintillator in the radon counting chamber is exposed to fluorescent or sunlight, the height of the pulse produced by an alpha particle may be increased. The increased amplitude is observed with Dumont and Fairchild 6292 photomultiplier tubes which have the S-11 photocathode, but not with the EMI-9856K and EMI-9956K photomultiplier tubes, which have the bialkali photocathode. The increase in pulse height is greatest at short times after exposure. The pulse height spectra at 2 to 20 min and at 16 h after exposure for 1 min to normal room levels of fluorescent light are shown in Figures 1 and 2 for the Dumont 6292 and the EMI 9856K photomultlier tubes, respectively. The total numbers of counts in the spectra for the early and late measurements are equal.

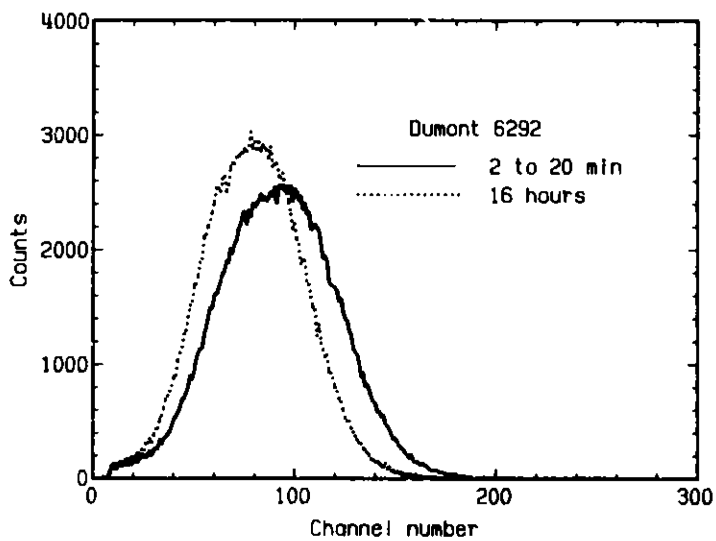

FIG. 1.--The pulse height spectra obtained from an alpha scintillation radon chamber at two different times after exposure to fluorescent light when a Dumont 6292 photomultiplier tube is used.

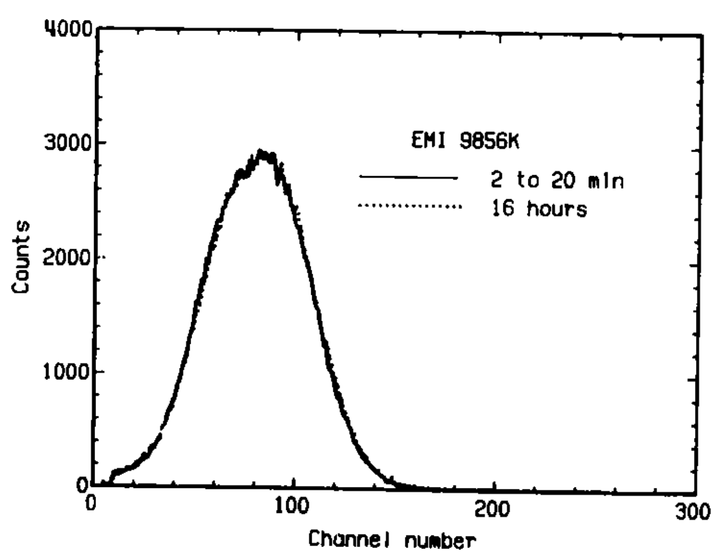

FIG. 2.--The pulse height spectra obtained from an alpha scintillation radon chamber at two different times after exposure to fluorescent light when an EMI-9856K photomultiplier tube is used.

The intensity and the half-life of the thermoluminescent component were determined at 24-25°C. A radon chamber with ^{239}Pu plated on the inside of the window, which yielded a counting rate of about 10,000 min^{-1}, was placed in the counter. About 16 h later, the lower level discriminator was adjusted until the counting rate was reduced to 30% of its normal value. This corresponds to about channel 90 in Figure 1. The radon chamber was removed and the scintillator exposed for 1 min to the overhead fluorescent light. The chamber was replaced in the counter, and the counting rate was recorded every 5 min for 20 h. These data, starting 10 min after exposure, were analyzed by a non-linear method of least squares. Two exponential terms were found; 66 ± 2% of the counts had a TL half-life of 22.7 ± 1.2 min, and 10 ± 2% of the counts had a TL half-life of 107.6 ± 1.2 min. From a plot of the data, it appears that the remaining 24% of the counts had a TL half-life of less than 3 min.

These observations strongly suggest that this is a thermoluminescent effect, since the frequency of the light emitted by the alpha particle appears to differ from the TL component, which is added by exposure to light. Further, since the pulses appear to be coincident, it is suggested that the alpha particle provides the local heating necessary for the release of the thermoluminescent part of the pulse. Since above 500 nm the sensitivity of the S-11 photocathode is greater than that of the bialkali photocathode, the frequency of the TL light would appear to have a longer wavelength than that from the alpha particles.

The thermoluminescent effect results in an increased efficiency of the alpha scintillation counter at short times after start of counting. The amount of efficiency change which is observed will not only vary with the degree of exposure to light and the duration of the counting interval, but will also be affected by the operating point selected. For a system in which the normal operating point has the lower level discriminator set so that 95% of the alpha pulses are accepted, then the limit is (100 - 95) or 5%.

The changing pulse height with time after the start of counting also affects the setting up of the counting system. The most common observation is that the system gain changes randomly in steps that range from 5% to 15%. Changes as large as this greatly exceed normal expectation for modern electronics.

Photomultiplier Tube Resolution

The spectra from a single alpha scintillation radon chamber were obtained for each of the counting systems. When they were compared, 4 of the 16 differed rather substantially from the others. Several of these were plotted, and the results indicated that the observed difference in spectral shape would affect the counting effeciency by as much as 3%.

The differences in the observed spectra were attributed to differences in the resolutions of the various photomultiplier-tube (PMT)/counting systems. The resolution of each was determined on a single counting system with a light pulser (battery-powered, light-emitting diode). With this system a good PMT had a resolution of 1.6% to 4.7%. The resolution for 8 of the 39 PMT tested ranged from 6% to 27%, and they were discarded since they would affect counting efficiency. However, some of these PMT had been in use for as long as 20 years or had been removed from service for other reasons. In addition, all non EMI-9856K or non EMI-9956K PMT were removed from service because of the thermoluminescent effect. The resolution of the amplifier-discriminator portion of each of the counting systems was evaluated with a single EMI-9856K PMT and the light pulser. Two of the systems had a resolution greater than that of the reference system. However, the resolution of both of these systems was restored when they were repaired.

The reproducibility of the results obtained by the use of different counting systems was evaluated by counting a single radon-filled alpha scintillation chamber on each of the 15 systems in service. The counting rate was about 4,000 cpm in each case. The results, corrected for growth and decay, are summarized in Table 1. The errors shown are those due only to counting and include the correction for the effect of the decay scheme.[3]

The weighted mean, the standard error expected from counting (SE_{int}), and standard error observed from the data (SE_{ext}), were calculated by standard methods. The standard deviation introduced by the various counting systems was estimated to be 0.14%. This is of no significance and we conclude that little or no variance is introduced by the use of multiple counting systems.

TABLE 1. Reproducibility of Results from Multiple Counting Systems

Counting System Number		^{222}Rn pCi ± σ^a
1		830.86 ± 3.40
2		827.76 ± 3.38
3		833.19 ± 3.38
4		840.30 ± 4.59
5		834.56 ± 4.57
6		836.26 ± 4.58
7		837.98 ± 4.58
8		831.27 ± 4.57
9		843.87 ± 4.60
10		837.30 ± 4.59
11		831.63 ± 4.58
12		837.00 ± 4.59
13		839.78 ± 4.60
14		835.57 ± 4.60
15		837.85 ± 4.60
	Mean	834.94
	SE_{int}	0.131%
	SE_{ext}	0.136%

[a]Counting error only.

Radon in Air Calibrations

An air sample with an accurately known concentration of ^{222}Rn was prepared using the following procedure. A known volume (5.000 ℓ) of water was added to a 10-L flask, and the displaced air was passed through an emanation flask containing an NBS standard solution of ^{226}Ra (about 850 pCi) and then through a small (6 mm) U-tube trap into a 20-L (16" X 24"), double layer 1-mil Saran bag with two 3/8" ports.* The trap was cooled with dry ice to remove water when 0% RH was desired; otherwise the dry ice was omitted. The bag was squeezed and manipulated to accelerate mixing. It was then allowed to stand for 1 h, so that further mixing and equilibration with room temperature could occur. Then, 16 to 32 radon chambers were filled by repeated evacuation and

*Available from the Anspec Company, Inc., 4126 Packard, P.O. Box 44, Ann Arbor, MI 48107. All bags are made to order.

filling. The barometric pressure and the temperature were recorded and used to adjust to a standard condition.

The leakage of radon through this bag has been measured by filling it with a known amount of ^{222}Rn, sealing it, placing it in a 50-L metal tank, and measuring the amount of radon that escapes. The amount of escaping radon determined on two occasions was 0.01% and 0.02% per day, respectively. All radon chambers were filled from this bag in 3 h or less so that no correction for radon loss was required.

The above calibration procedure was repeated on four different dates using the same six counting chambers. For this study, each radon chamber was counted on the same counting system. The calibration factor, in cph/pCi/L (counts per hour per picocurie ^{222}Rn per liter at a pressure of 740 mm, a temperature of 27°C, and 50% RH), was determined for each calibration for each chamber. The individual results, the weighted mean and internal, external, and systematic standard errors are shown in Table 2. In contrast to the observations with multiple counting systems shown in Table 1, the results of these measurements suggest significant systematic standard errors, ranging from 0.4% to 1.2% and with a mean of 0.66%. These values suggest a standard deviation of 1.1%, which still is sufficiently small that the factors affecting precision appear relatively well understood. Therefore, no further study is anticipated.

TABLE 2. Precision of Radon in Air Calibration

	Chamber 201 Cph ± σ[a]	Chamber 202 Cph ± σ[a]	Chamber 203 Cph ± σ[a]	Chamber 204 Cph ± σ[a]	Chamber 206 Cph ± σ[a]	Chamber 211 Cph ± σ[a]
	32.41 ± 0.16	33.00 ± 0.17	32.60 ± 0.16	32.20 ± 0.16	32.62 ± 0.15	32.01 ± 0.15
	32.57 ± 0.22	32.90 ± 0.22	31.92 ± 0.22	32.04 ± 0.22	32.05 ± 0.22	31.84 ± 0.22
	32.09 ± 0.14	32.26 ± 0.14	31.81 ± 0.13	31.01 ± 0.13	31.76 ± 0.13	31.32 ± 0.14
	32.76 ± 0.16	33.10 ± 0.16	32.64 ± 0.16	32.62 ± 0.16	31.79 ± 0.16	31.91 ± 0.16
Mean	32.41	32.75	32.22	31.84	32.04	31.74
SE_{int}	0.25%	0.25%	0.25%	0.25%	0.25%	0.25%
SE_{ext}	0.47%	0.65%	0.70%	1.22%	0.66%	0.54%
SE_{sys}	0.40%	0.60%	0.66%	1.19%	0.61%	0.48%

[a]Counting error only. Cph is counts per hour per pCi ^{222}Rn per liter at 740 mm Hg, 27°C, and 50% RH.

Acknowledgements

Special thanks are due J. E. Miranda for designing and constructing the light pulser used in this study.

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APPENDIX A. Exposure Data for Radium Patients

Table A1 (presented at the end of this appendix) summarizes exposure data collected as of 31 December 1983 for 2400 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 analytic 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 1983 annual report[1] listed 2312 cases. The radium contents of 88 persons were measured for the first time in 1983. Each of the 88 additional cases is identified by an asterisk following the year of measurement. There were followup examinations and content measurements in 1983 on 7 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 of Table A1, the type of exposure to radium (dial painting, medical, etc.) is indicated by code digits defined in Table A2; if more than one type of exposure occurred, two non-zero digits are given. 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 first exposed before the year 1926 but whose exposure extended into 1926 or beyond, the duration used in calculating the dose corresponds to the exposure terminating in 1926.

The ^{226}Ra body contents, given in column 9 of Table A1, are expressed as nanocuries (nCi) of ^{226}Ra present in the year of measurement (shown in the preceding column). These entries may be converted to becquerels (Bq) by multiplication by 37. If several measurements over a period of years had been made for a given case, the result (and year) 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 A3.

TABLE A2. Type of Exposure to ^{226}Ra or ^{228}Ra or Both for Table A1.

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 previously exposed female

TABLE A3. Principal Types of Measurement of Body Contents of ^{226}Ra and ^{228}Ra for Table A1.

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	. . . .

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 A4, and the errors shown include systematic errors as well as replication errors.

TABLE A4. Error Ranges for ^{226}Ra Body Contents and $^{228}Ra/^{226}Ra$ Ratios in Table A1.

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[b]
9	Initial ratio of ^{228}Ra to ^{226}Ra probably ≤ 0.20[b]
L	90% confidence limits extend from 0 nCi or Bq to an upper limit between 4 and 8 nCi (between 150 and 300 Bq)

[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 A1 by the factor; the square of this factor is used to obtain the corresponding limits for two standard errors.

[b]Ref. 2.

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 of 4 is shown in the ^{226}Ra column, but the letter L means that the 90% confidence limits extend from 0 nCi to an upper limit somewhere between 4 and 8 nCi. There are 53 of these cases that 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 contents have a standard deviation of 1 to 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 contents.

Each entry in column 11 of Table A1 is the activity ratio 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 A3 and A4. The letter 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 ^{226}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 A1 give quantities calculated from the measured body contents 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 microcuries (μCi), calculated by applying the Norris retention function[3] to values of body contents usually measured long after the initial intake. Multiplication of these entries by 37 converts them to kilobecquerels (kBq). The skeletal rads, given in the last two columns for ^{226}Ra and ^{228}Ra

separately, refer to the average absorbed dose to the skeleton[4] -- either up to the date of death or, for the living subjects, through 1983. These may be converted to grays (Gy) by multiplication by 0.01. Except for the fetal skeleton (case 01-579), the results in the last two columns were calculated with standard skeletal masses of 5 kg for females and 7 kg for males.

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TABLE A1. Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
00-001	M	1883	1928	06	1913	780	1967	13000	F4	0.00700	F3	1016	1298	2893	8286
00-002	F	1896	1922	01	1917	223	1966	16000	F4	0.00110	F3	996	310	2313	1369
00-003	F	1894	1927	01	1917	104	1966	7000	F4	0.01200	F1	872	3570	4074	40367
00-004	F	1900	1931	01	1917	88	1963	9000	F4	0.00080	F1	1367	264	8050	3481
00-005	F	1901	1939	01	1917	300	1963	1400	F4	0.00700	Z7	258	331	1913	4731
00-006	F	1903	1930	01	1918	128	1969	2610	A1	0.00536	A1	357	808	1859	9901
00-007	F	1903	1935	01	1919	104	1963	1000	F4	0.01000	Z7	163	302	1038	4124
00-008	M	1890	1938	06	1915	598	1972	3045	A1	0.00288	A3	525	682	2601	6775
00-009	F	1900	1928	01	1918	266	1969	2650	A1	0.00490	A2	295	504	1224	5064
00-017	F	1899	1924	01	1917	156	1970	17000	A1	0.00069	Z7A	1626	580	5650	4765
00-019	F	1895	1946	01	1917	260	1976	2400	F2	0.00140	F4	525	693	4790	10252
00-020	M	1888	1925	06	1912	676	1969	920	A1	0.00228	A6	67	49	174	286
00-022	F	1869	1925	01	1917	377	1960	10000	F4	0.01000	F1	752	807	2223	5201
00-023	F	1900	1929	01	1917	65	1978	7214	A1	0.00007	F2A	1016	116	5475	1453
00-027	F	1902	1942	01	1918	130	1970	2500	A1	0.00256	F1A	505	615	4187	8989
00-028	F	1902	1933	01	1917	279	1969	10000	F4	0.00036	F1	1522	214	9016	2816
00-029	F	1900		01	1917	409	1969	17	G6	0.0	Z9	5	0	80	0
00-033	M	1868	1922	06	1919	156	1970	6	A6	0.00300	Z7A	0	0	0	0
00-034	F	1882	1943	07	1917	232	1979	1	A6	0.00060	Z7	0	0	1	2
01-001	F	1878	1949	05	1922	+0	1972	15400	A1	0.0	Z9A	3403	0	31456	0
01-002	F	1906	1939	01	1922	676	1936	18000	B2	0.01950	F3	2599	214	16586	2919
01-003	M	1888	1956	05	1925	304	1967	12800	A1	0.00037	A3	2882	120	19507	1273
01-004	F	1869	1953	04	1918	+0	1941	10500	E4	0.0	Z9	2134	0	23320	0
01-005	M	1877	1939	02	1927	12	1939	5000	E4	0.50000	E4	721	1530	2850	13918
01-006	F	1899	1938	01	1919	260	1970	3590	A1	0.00144	A3	612	314	4144	4361
01-007	F	1886	1949	05	1926	+0	1967	3620	A1	0.0	Z9A	736	0	6142	0
01-008	F	1900	1958	01	1917	78	1960	6000	F2	0.00067	F3	1632	186	19519	2790
01-009	F	1898	1945	01	1918	52	1960	6500	F4	0.00050	F2	1422	110	12991	1634
01-010	M	1882	1956	04	1926	+0	1967	5200	A1	0.0	Z9A	1214	0	8574	0
01-011	F	1872	1937	04	1919	156	1975	6000	A1	0.0	Z9A	1025	0	6942	0
01-012	F	1867	1956	05	1922	+0	1970	5800	A1	0.0	Z9A	1445	0	15491	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
01-014	F	1901	1949	01	1916	156	1968	2240	A1	0.00036	F3	536	89	5471	1328
01-015	M	1888	1967	01	1917	1664	1961	0	C6	0.0	Z9	0	0	0	0
01-016	F	1891	1966	01	1921	208	1973	1940	A1	0.00245	F2	546	578	6817	8678
01-017	F	1883	1976	02	1926	156	1977	1120	A1	0.00156	B2	336	214	4534	3221
01-018	M	1889	1958	06	1911	2340	1950	1250	B2	0.0	Z9B	185	0	1110	0
01-019	F	1903	1936	01	1922	253	1965	240	A1	0.02[illegible]8	A2	35	147	193	1879
01-020	F	1905	1956	05	1923	5	1950	1500	E4	0.0	Z9	331	0	3479	0
01-021	F	1887	1973	01	1916	104	1965	1250	E4	0.0	Z9	373	0	5531	0
01-022	F	1900	1951	01	1917	110	1968	600	A2	0.0	Z9A	147	0	1544	0
01-024	F	1901	1956	01	1916	308	1943	1140	B2	0.02190	F3	237	94	2682	1403
01-025	F	1886	1952	05	1924	+0	1951	1200	B2	0.00100	F3	265	7	2509	105
01-026	F	1905	1958	01	1925	156	1950	700	B2	0.03000	D5	147	87	1531	1295
01-027	M	1889	1957	06	1912	1040	1960	500	A2	0.0	Z9F	125	0	973	0
01-028	M	1879	1965	06	1912	260	1953	250	E4	0.0	Z9	66	0	658	0
01-029	M	1876	1958	06	1902	+0	1950	300	G4	0.0	Z9	89	0	948	0
01-030	M	1882	1952	07	1936	0	1950	20	F4	0.0	Z9	3	0	15	0
01-031	F	1906	1934	01	1925	4	1975	910	A1	0.01130	A1	113	557	528	6296
01-032	F	1908	1940	01	1924	201	1968	1450	A1	0.02800	A1	236	1228	1506	16742
01-033	F	1908	1931	01	1923	42	1963	2472	A1	0.05153	A1	282	1793	1192	18509
01-034	F	1913		01	1929	18	1965	8	G6	0.01000	Z8	2	2	30	24
01-035	F	1901	1972	01	1920	19	1971	0	B6	0.01860	Z2B	0	0	0	0
01-037	F	1908		01	1928	26	1974	0	B6	0.00327	Z8B	0	0	0	0
01-038	F	1910		01	1927	111	1959	8	B2	0.02000	Z8B	2	2	28	24
01-039	F	1915		07	1934	1092	1972	1	B6	0.0	Z9B	0	0	3	0
01-040	F	1907	1929	01	1923	60	1963	4300	A1	0.05209	A1	412	2585	1422	21160
01-041	F	1909		01	1927	22	1971	0	B6	0.00470	Z8B	0	0	0	0
01-043	F	1912		01	1927	8	1958	9	B6	0.02200	Z8B	2	2	32	30
01-044	F	1904		01	1924	22	1959	4	B3	0.08000	Z2B	1	6	15	83
01-045	F	1889	1980	01	1922	237	1959	0	B6	0.08000	Z2B	0	0	0	0
01-046	F	1903	1943	01	1920	657	1963	551	A1	0.05607	A1	104	731	793	10502
01-047	F	1896		01	1920	367	1962	80	G4	0.05700	Z2	21	136	332	2048

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
01-048	F	1900	1979	01	1920	206	1957	140	B2	0.09290	F2	35	230	532	3456
01-049	F	1903	1937	01	1920	1	1960	1000	A1	0.07300	A2	174	1641	1198	22993
01-050	F	1911		01	1925	10	1976	1	B6	0.00258	Z8B	0	0	5	6
01-051	F	1904	1977	01	1923	162	1977	120	A2	0.01100	A2	37	243	533	3648
01-052	F	1910	1930	01	1924	144	1965	2000	A1	0.03500	A1	183	824	602	6301
01-054	F	1909	1937	01	1924	202	1965	2100	A1	0.03714	A1	304	1457	1692	18610
01-055	F	1907		01	1925	85	1976	4	B3	0.01024	Z2B	1	6	18	88
01-056	F	1904	1978	01	1920	364	1965	134	B1	0.03432	B2	37	206	546	3093
01-057	F	1908	1931	01	1924	81	1963	4900	A1	0.05163	A1	504	2704	1887	24482
01-059	F	1905	1967	01	1920	299	1964	180	B1	0.04277	B2	49	307	628	4608
01-060	F	1909		07	1928	20	1974	0	B6	0.00330	Z8B	0	0	0	0
01-063	F	1911	1979	01	1927	213	1976	34	B1	0.00154	Z8B	10	5	138	69
01-066	F	1904		01	1925	0	1980	0	C6	0.00159	Z8C	0	0	0	0
01-069	F	1905		17	1922	107	1976	0	B6	0.01024	Z2B	0	0	0	0
01-070	F	1910		01	1927	63	1973	1	B6	0.00370	Z8B	0	0	4	4
01-071	F	1908	1967	01	1927	6	1958	0	B6	0.02300	Z8B	0	0	0	0
01-072	F	1899		01	1921	130	1954	100	E4	0.10000	D5	24	114	377	1710
01-073	F	1900	1969	01	1921	122	1966	87	B1	0.03563	B2	25	181	327	2722
01-074	F	1909		01	1927	47	1979	4	B3	0.00172	Z8B	1	1	18	17
01-075	F	1902		01	1922	52	1979	4	B6	0.00713	Z2B	1	9	20	134
01-078	F	1909		01	1925	50	1978	3	B6	0.00193	Z8B	1	1	14	16
01-079	F	1901	1943	01	1920	176	1960	750	F4	0.09070	F1	146	1387	1164	20106
01-080	F	1902		01	1921	204	1968	106	B1	0.02075	B3	31	150	475	2255
01-081	F	1907		01	1923	11	1959	7	B6	0.08000	Z2B	2	11	28	170
01-082	F	1902	1935	01	1919	230	1963	1030	A1	0.03786	A1	160	956	968	12727
01-084	F	1904		01	1923	712	1974	46	B2	0.01297	Z2B	14	74	213	1110
01-085	F	1913		01	1927	47	1958	6	B6	0.02200	Z8B	1	1	21	19
01-086	F	1907	1966	01	1925	4	1959	0	B6	0.08000	Z2B	0	0	0	0
01-087	F	1905	1979	01	1921	344	1964	780	F4	0.03690	F1	213	1061	3140	15955
01-090	F	1910		01	1927	90	1977	5	B3	0.00218	Z8B	2	1	22	19
01-091	F	1907		01	1927	264	1979	0	B6	0.00179	Z8B	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
01-092	F	1906	1976	01	1922	24	1971	2	B6	0.01860	Z2B	1	4	9	63
01-093	F	1904		01	1926	8	1971	0	B6	0.00460	Z8B	0	0	0	0
01-094	F	1888	1966	01	1921	128	1964	11	G4	0.04400	Z2	3	21	39	322
01-095	F	1907	1977	01	1922	34	1975	6	B2	0.01163	Z2B	2	13	27	198
01-096	F	1909		01	1927	310	1960	27	D2	0.01800	Z8	6	4	90	64
01-097	F	1905		01	1921	110	1963	122	B1	0.03852	B2	33	187	525	2809
01-099	F	1905	1945	01	1924	18	1963	164	A1	0.05365	A2	32	191	248	2760
01-100	F	1905	1967	01	1924	36	1957	34	B2	0.13200	D5	8	58	103	872
01-101	F	1905		01	1924	4	1959	0	B6	0.08000	Z2B	0	0	0	0
01-103	F	1903	1946	17	1922	172	1978	374	A1	0.00800	Z2A	75	440	613	6412
01-105	F	1898	1945	01	1921	21	1963	460	A1	0.05217	A1	95	801	812	11743
01-106	F	1902	1977	01	1924	155	1959	10	B2	0.08000	Z2B	2	12	35	187
01-110	F	1909		01	1925	93	1979	1	B6	0.00172	Z8B	0	0	5	5
01-111	F	1910		01	1927	16	1980	1	C6	0.00152	Z8C	0	0	6	5
01-112	F	1908	1955	01	1924	835	1960	80	F4	0.07000	F1	19	92	185	1368
01-113	F	1912	1983	01	1928	5	1959	3	B6	0.02000	Z8B	1	1	10	9
01-115	F	1908	1944	01	1924	330	1963	472	A1	0.03093	A1	87	272	642	3883
01-116	F	1899	1965	01	1920	459	1955	290	G4	0.10000	G5	70	333	860	5000
01-118	F	1909	1971	01	1923	13	1959	0	B6	0.08000	Z2B	0	0	0	0
01-119	F	1899	1966	01	1920	14	1958	5	B6	0.09000	Z2B	1	12	17	178
01-120	F	1910		01	1925	125	1959	10	B2	0.02000	Z8B	2	3	37	44
01-122	F	1912		01	1927	49	1981	9	C3	0.00141	Z8B	3	3	40	38
01-123	F	1889	1980	01	1923	11	1976	0	B6	0.01024	Z2B	0	0	0	0
01-124	F	1909		01	1927	64	1979	41	B1	0.00180	Z8B	13	12	187	177
01-125	F	1911		01	1927	6	1979	0	B6	0.00179	Z8B	0	0	0	0
01-126	F	1903	1969	01	1922	416	1969	150	A1	0.02667	A3	43	271	556	4074
01-127	F	1908		01	1927	9	1974	1	B6	0.00330	Z8B	0	0	4	4
01-128	F	1910		01	1927	4	1959	2	B6	0.02000	Z8B	0	0	7	7
01-129	F	1906	1934	01	1923	4	1977	2	F6	0.00907	Z2F	0	2	2	25
01-130	F	1909		01	1926	196	1964	11	B2	0.01140	Z8B	3	3	42	39
01-132	F	1908	1944	01	1923	76	1966	1327	A1	0.03496	A1	253	1505	1946	21690

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
01-133	F	1910		01	1926	65	1958	13	B2	0.03000	Z8B	3	4	46	64
01-136	F	1907		01	1923	185	1978	30	B1	0.00674	B3	9	42	145	638
01-137	F	1901		01	1923	714	1977	5	B3	0.00902	Z2B	2	8	24	125
01-138	F	1883	1963	04	1919	4	1959	6	G6	0.0	Z9	1	0	19	0
01-139	M	1881	1964	02	1928	130	1962	1270	B1	0.01417	B2	310	235	2409	2509
01-140	F	1890		01	1919	78	1975	0	B6	0.0	Z9B	0	0	0	0
01-141	M	1886	1978	02	1928	130	1979	12	A1	0.00180	Z5B	4	3	35	29
01-142	F	1899		01	1917	52	1969	0	G6	0.0	Z9	0	0	0	0
01-143	F	1904		01	1921	65	1976	1	B6	0.0	Z9B	0	0	5	0
01-144	F	1897	1973	04	1922	26	1971	694	B1	0.0	Z9B	209	0	2902	0
01-145	F	1900	1957	01	1918	60	1966	6331	A1	0.00077	A3	1681	413	19506	6195
01-146	F	1882	1967	02	1927	156	1968	100	A1	0.00870	Z5A	27	28	309	420
01-147	F	1902		01	1917	26	1965	52	G4	0.0	Z9	15	0	255	0
01-148	F	1907		06	1936	364	1958	40	G4	0.0	Z9	7	0	91	0
01-149	F	1888	1959	01	1919	26	1969	1630	A1	0.00533	A3	440	995	5226	14933
01-150	F	1881	1979	04	1930	104	1970	3	B6	0.0	Z9B	1	0	11	0
01-151	F	1905		06	1927	52	1981	0	C6	0.0	Z9C	0	0	0	0
01-152	F	1904		01	1920	17	1977	2	C6	0.00159	Z5B	1	1	10	16
01-153	M	1890	1964	06	1920	104	1963	280	B1	0.00036	B6	78	5	694	50
01-154	M	1896	1968	06	1923	+0	1959	0	G6	0.01500	Z7	0	0	0	0
01-156	F	1900	1959	01	1918	156	1959	40	G6	0.0	Z9	11	0	127	0
01-157	F	1894	1982	02	1925	13	1975	49	B2	0.00139	Z5B	15	9	223	134
01-158	F	1901	1977	06	1920	52	1959	1	G6	0.0	Z9	0	0	4	0
01-159	F	1915		01	1935	220	1980	5	C3	0.0	Z9C	1	0	16	0
01-160	F	1873	1965	02	1925	+0	1959	130	B1	0.02000	B3	32	40	386	607
01-161	F	1896	1973	01	1918	17	1959	1	B6	0.0	Z9B	0	0	4	0
01-162	M	1898	1966	06	1920	364	1959	95	B1	0.01000	Z7B	24	17	214	187
01-163	F	1903	1983	01	1920	26	1972	2	B6	0.00360	Z7B	1	1	10	18
01-164	F	1900	1972	01	1918	39	1959	9	B2	0.0	Z9B	2	0	35	0
01-165	F	1904		01	1922	22	1981	13	C3	0.0	Z9C	4	0	67	0
01-166	F	1897	1969	01	1916	26	1959	0	B6	0.0	Z9B	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
01-168	F	1895		06	1919	468	1966	1	B6	0.0	Z9B	0	0	4	0
01-169	F	1918		01	1936	69	1975	0	B6	0.0	Z9B	0	0	0	0
01-170	M	1893	1966	05	1940	0	1959	2	G6	0.0	Z9	0	0	2	0
01-171	M	1895	1975	45	1914	6	1958	1500	B1	0.0	Z9B	427	0	4788	0
01-172	F	1898	1968	01	1916	136	1961	1960	B1	0.00112	B3	556	126	7736	1892
01-173	M	1881	1959	06	1917	1300	1958	70	G4	0.0	Z9	15	0	108	0
01-175	F	1900	1966	02	1927	13	1965	1710	B1	0.00760	B2	451	343	5269	5139
01-176	F	1893	1969	01	1917	104	1969	0	G6	0.0	Z9	0	0	0	0
01-177	M	1915		06	1936	312	1969	61	B1	0.0	Z9B	14	0	129	0
01-178	M	1939		07	1958	0	1973	2	B6	0.0	Z9C	0	0	2	0
01-179	F	1890	1966	45	1924	58	1959	2000	B1	0.0	Z9B	502	0	6115	0
01-180	F	1900		01	1918	26	1971	3	B3	0.0	Z9B	1	0	15	0
01-181	M	1913	1963	06	1940	130	1959	220	B1	0.0	Z9B	39	0	225	0
01-182	M	1902	1959	02	1936	+0	1959	7	D3	0.02600	Z5D	1	1	8	6
01-183	F	1901	1969	01	1915	78	1969	203	A1	0.0	Z9A	64	0	917	0
01-184	M	1887	1969	05	1922	10	1968	48	B2	0.0	Z9B	14	0	132	0
01-185	M	1881	1962	06	1912	+0	1959	40	G6	0.0	Z9	12	0	116	0
01-186	M	1925		06	1943	416	1976	19	B2	0.0	Z9B	4	0	35	0
01-187	M	1917		06	1943	78	1980	23	C2	0.0	Z9C	6	0	49	0
01-188	F	1886	1979	04	1933	3	1959	4	G6	0.0	Z9	1	0	11	0
01-189	M	1921		07	1958	0	1973	0	B6	0.0	Z9C	0	0	0	0
01-190	F	1927		07	1958	0	1973	0	B6	0.0	Z9C	0	0	0	0
01-191	M	1897	1966	06	1913	78	1959	4	B6	0.0	Z9B	1	0	12	0
01-192	F	1902	1962	01	1925	52	1959	34	B2	0.0	Z9B	8	0	94	0
01-193	F	1886	1960	06	1917	156	1974	31	A2	0.0	Z9	9	0	105	0
01-194	M	1898	1982	01	1916	676	1972	0	B6	0.0	Z9B	0	0	0	0
01-195	F	1893	1958	06	1912	520	1959	1	A6	0.0	Z9	0	0	3	0
01-196	M	1907		02	1930	20	1972	69	B1	0.00540	Z5B	19	17	195	179
01-197	F	1883	1965	04	1916	+0	1958	16	G6	0.0	Z9	4	0	61	0
01-198	F	1888	1972	45	1913	+0	1959	0	B6	0.0	B6	0	0	0	0
01-200	F	1910		01	1925	220	1977	3	B3	0.00914	Z2B	1	4	14	67

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
01-201	F	1911		01	1925	55	1959	26	B2	0.02100	Z8B	6	8	97	119
01-203	F	1908	1983	01	1923	1	1973	0	B6	0.01470	Z2B	0	0	0	0
01-204	F	1901	1980	01	1917	22	1959	5	B3	0.0	Z9B	1	0	22	0
01-205	M	1921	1974	06	1951	52	1972	7	B3	0.0	Z9C	1	0	8	0
01-206	M	1896	1982	06	1918	17	1981	11	C3	0.0	Z9C	4	0	42	0
01-207	F	1909	1967	01	1927	9	1959	4	B3	0.02000	Z8B	1	1	11	14
01-208	M	1901	1972	06	1939	1144	1974	818	A1	0.0	Z9	157	0	900	0
01-209	F	1908	1975	01	1926	16	1959	0	B6	0.02700	Z8B	0	0	0	0
01-210	M	1878	1971	06	1918	2028	1959	12	B2	0.0	Z9B	2	0	15	0
01-216	F	1903	1963	01	1924	4	1959	0	B6	0.08000	Z2B	0	0	0	0
01-217	M	1894	1971	01	1914	208	1959	5	B3	0.0	Z9B	1	0	15	0
01-218	M	1924		06	1950	780	1974	0	B6	0.0	Z9B	0	0	0	0
01-219	F	1910		01	1927	10	1976	0	B6	0.00246	Z8B	0	0	0	0
01-220	F	1907		01	1924	26	1959	2	B6	0.07100	Z2B	1	2	8	37
01-221	M	1892	1970	06	1916	520	1967	10	B2	0.00320	Z7B	3	2	28	25
01-222	F	1910		01	1925	17	1964	4	CL	0.04400	Z2C	1	5	16	79
01-223	F	1912		01	1927	7	1963	0	G6	0.01200	Z8	0	0	0	0
01-225	F	1906		01	1931	35	1959	0	D6	0.0	Z9D	0	0	0	0
01-226	F	1911		01	1927	22	1976	0	B6	0.00258	Z8B	0	0	0	0
01-227	F	1908		07	1933	2184	1975	0	B6	0.0	Z9B	0	0	0	0
01-228	F	1906		01	1926	61	1972	6	B6	0.00420	Z8B	2	2	26	27
01-229	F	1903		01	1923	2	1959	8	B2	0.08000	Z2B	2	13	32	196
01-230	F	1913		01	1927	19	1978	0	B6	0.00203	Z8B	0	0	0	0
01-231	F	1910	1969	01	1930	84	1959	0	B6	0.0	Z9B	0	0	0	0
01-232	F	1909	1961	04	1926	43	1959	0	B6	0.0	Z9B	0	0	0	0
01-233	F	1912	1973	01	1927	145	1959	2	B6	0.02000	Z8B	0	0	6	6
01-234	F	1913	1966	01	1927	1	1959	0	B6	0.02000	Z8B	0	0	0	0
01-235	F	1908		01	1925	8	1959	1	B6	0.08000	Z2B	0	1	4	19
01-236	F	1910	1976	01	1927	9	1965	1	G6	0.01000	Z8	0	0	4	4
01-237	F	1907		01	1927	8	1979	0	B6	0.00179	Z8B	0	0	0	0
01-238	F	1896	1967	01	1920	2	1959	1	B6	0.08000	Z2B	0	2	4	37

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
01-239	F	1901	1958	01	1917	78	1957	830	F4	0.00157	F3	223	41	2665	620
01-240	F	1910		01	1927	13	1971	7	D3	0.00450	Z8D	2	2	30	28
01-243	M	1873	1959	06	1905	520	1958	15	G6	0.0	Z9	4	0	43	0
01-244	F	1901	1979	01	1927	18	1975	1	B6	0.00307	Z8	0	0	4	5
01-245	F	1920		01	1957	30	1969	0	G6	0.0	Z9	0	0	0	0
01-246	F	1885	1970	06	1915	39	1967	3	B6	0.0	Z9B	1	0	14	0
01-247	M	1901		06	1923	689	1981	4	C3	0.00107	Z7B	1	1	13	7
01-248	F	1903		01	1917	208	1976	21	B2	0.0	Z9B	7	0	111	0
01-249	M	1928		08	1928	39	1967	2	G6	0.02700	Z2	1	2	6	17
01-250	M	1894		06	1916	520	1975	0	B6	0.0	Z9B	0	0	0	0
01-251	M	1890	1965	06	1912	156	1974	11	A2	0.0	Z9	3	0	34	0
01-252	F	1898		01	1917	104	1976	22	B1	0.0	Z9B	7	0	118	0
01-253	F	1898	1964	01	1916	104	1959	22	G6	0.0	Z9	6	0	79	0
01-254	F	1910	1982	01	1927	2	1971	1	B6	0.00460	Z8B	0	0	4	4
01-255	F	1920		01	1942	52	1975	0	B6	0.0	Z9B	0	0	0	0
01-256	M	1919	1982	06	1949	208	1959	7	G6	0.0	Z9	1	0	6	0
01-257	M	1885	1962	06	1941	624	1959	0	G6	0.0	Z9	0	0	0	0
01-258	M	1903		67	1923	1092	1969	17	G6	0.0	Z9	4	0	42	0
01-259	F	1910		06	1927	416	1977	0	B6	0.0	Z9	0	0	0	0
01-260	F	1891	1960	04	1918	50	1959	8	G6	0.0	Z9	2	0	25	0
01-261	F	1909	1969	01	1927	2	1959	0	B6	0.02000	Z8B	0	0	0	0
01-262	F	1895		06	1918	0	1969	22	G4	0.0	Z9	7	0	111	0
01-263	F	1897	1976	01	1917	17	1976	9	B6	0.0	Z9B	3	0	46	0
01-264	M	1906	1967	01	1944	770	1964	90	G4	0.0	Z9	13	0	59	0
01-265	F	1902		01	1919	2	1959	3	B6	0.08000	Z2B	1	8	13	126
01-266	F	1904	1961	01	1923	3	1959	1	B6	0.08000	Z2B	0	2	3	24
01-267	F	1904		01	1926	104	1966	45	G4	0.0	Z9	12	0	179	0
01-268	F	1901	1968	01	1917	208	1967	100	B2	0.01000	B2	30	101	405	1518
01-269	M	1911		06	1932	624	1979	2	B6	0.0	Z9B	1	0	5	0
01-270	F	1901		01	1943	32	1976	4	B3	0.0	Z9	1	0	12	0
01-271	F	1899		01	1917	86	1979	2	B6	0.0	Z9B	1	0	11	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
01-272	M	1888		06	1956	130	1959	39	G6	0.0	Z9	2	0	12	0
01-273	F	1907		01	1924	1	1959	2	B6	0.08400	Z2B	1	3	8	45
01-274	F	1906	1980	01	1922	5	1978	0	B6	0.00799	Z2B	0	0	0	0
01-275	M	1930		06	1959	+0	1959	23	G6	0.0	Z9	0	0	0	0
01-276	M	1930	1962	06	1945	208	1959	30	G6	0.0	Z9	4	0	20	0
01-277	F	1909		01	1925	6	1978	5	C6	0.00828	Z2	1	7	22	112
01-278	F	1904	1976	06	1925	0	1969	10	G6	0.0	Z9	3	0	40	0
01-279	M	1901	1969	06	1928	1404	1966	0	G6	0.0	Z9	0	0	0	0
01-280	F	1905		01	1926	7	1971	0	B6	0.00460	Z8B	0	0	0	0
01-282	M	1893	1973	06	1916	156	1972	42	B2	0.0	Z9B	13	0	141	0
01-283	F	1895	1971	07	1918	52	1959	3	B6	0.0	Z9B	1	0	12	0
01-284	M	1892	1970	06	1943	780	1959	5	B3	0.0	Z9B	1	0	3	0
01-285	F	1900		01	1923	1	1960	4	B6	0.07100	Z2B	1	7	16	100
01-287	F	1908		01	1927	674	1977	2	B6	0.00232	Z8C	1	0	8	3
01-288	F	1894	1970	01	1926	2	1960	2	C6	0.02400	Z8C	1	1	6	11
01-289	F	1899	1975	01	1919	80	1971	4	B3	0.01860	Z2B	1	12	18	175
01-291	F	1910	1969	01	1928	17	1960	5	B6	0.01800	Z8B	1	1	15	16
01-293	F	1911		01	1924	11	1978	0	B6	0.00804	Z2B	0	0	0	0
01-294	F	1912		01	1927	52	1971	3	B3	0.00450	Z8B	1	1	13	11
01-295	F	1910		01	1927	14	1981	0	C6	0.00141	Z8C	0	0	0	0
01-296	F	1908		01	1927	5	1960	0	B6	0.01800	Z8B	0	0	0	0
01-297	F	1901		01	1921	122	1960	16	B2	0.09375	B3	4	39	66	589
01-299	F	1896		01	1917	104	1968	3	G6	0.0	Z9	1	0	15	0
01-301	F	1904		05	1926	5	1969	17	G4	0.0	Z9	5	0	72	0
01-302	F	1899	1966	05	1927	10	1968	2850	A1	0.0	Z9A	761	0	8910	0
01-303	M	1919		01	1940	104	1974	0	B6	0.0	Z9B	0	0	0	0
01-305	M	1925	1968	06	1946	1040	1972	87	F4	0.0	Z9B	11	0	43	0
01-306	M	1928		06	1955	364	1979	22	B2	0.0	Z9B	4	0	26	0
01-307	M	1930		06	1957	104	1975	4	B6	0.0	Z9B	1	0	4	0
01-308	M	1918	1957	06	1943	728	1958	1200	F4	0.0	Z9F	90	0	247	0
01-309	F	1908	1973	01	1923	2	1961	2	B6	0.06200	Z2B	1	3	7	50

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
01-310	F	1928		08	1928	39	1975	0	B6	0.01148	Z2	0	0	0	0
01-311	F	1911		01	1927	2	1961	1	B6	0.01500	Z8B	0	0	4	4
01-312	F	1907		01	1925	13	1976	0	B6	0.0	Z9B	0	0	0	0
01-313	M	1892	1981	06	1911	624	1961	3	B3	0.0	Z9B	1	0	10	0
01-314	F	1909		01	1924	0	1961	1	B6	0.06200	Z2B	0	1	4	22
01-324	F	1907		01	1923	15	1962	1	G6	0.05700	Z2	0	2	4	26
01-326	F	1896	1972	02	1925	156	1966	100	G4	0.01100	Z5	27	36	349	539
01-327	F	1908		01	1927	1	1965	0	G6	0.01000	Z8	0	0	0	0
01-330	M	1915		06	1942	364	1976	66	B2	0.0	Z9B	16	0	127	0
01-331	M	1901		02	1927	+0	1966	80	G4	0.01100	Z5	21	27	227	290
01-332	F	1912	1971	01	1927	52	1965	0	G6	0.01000	Z8	0	0	0	0
01-333	F	1905		01	1924	10	1981	1	C6	0.00589	Z2C	0	2	5	32
01-335	F	1899		16	1917	78	1980	3	C6	0.0	Z9C	1	0	18	0
01-336	M	1899		06	1945	1092	1979	41	B1	0.0	Z9B	8	0	54	0
01-341	M	1883	1980	06	1943	176	1961	5	B3	0.0	Z9B	1	0	7	0
01-342	M	1897		06	1944	56	1961	1	B6	0.0	Z9B	0	0	1	0
01-343	F	1873	1954	04	1927	+0	1963	0	F6	0.0	Z9	0	0	0	0
01-344	F	1904	1976	01	1922	19	1962	7	G6	0.05700	Z2	2	14	27	206
01-345	F	1910	1977	01	1924	1	1962	4	G6	0.05700	Z2	1	6	15	92
01-346	F	1911		01	1927	17	1962	44	G6	0.01700	Z8	11	13	165	196
01-347	M	1896	1968	06	1926	1872	1962	14	B2	0.0	Z9B	2	0	10	0
01-348	F	1902	1973	01	1924	19	1966	112	B1	0.03482	B2	31	175	422	2628
01-349	F	1907	1967	01	1924	10	1966	93	B1	0.03225	B2	26	136	322	2043
01-350	F	1898	1973	01	1923	108	1962	0	G6	0.05700	Z2	0	0	0	0
01-351	F	1906		01	1923	3	1962	0	G6	0.05700	Z2	0	0	0	0
01-352	M	1922	1983	06	1940	338	1962	191	B1	0.0	Z9B	35	0	295	0
01-356	M	1912	1973	06	1937	572	1969	23	B2	0.0	Z9B	5	0	36	0
01-357	F	1907	1970	07	1927	408	1962	0	G6	0.01400	Z8	0	0	0	0
01-358	F	1906	1978	07	1923	168	1962	0	G6	0.05700	Z2	0	0	0	0
01-359	F	1908		01	1925	55	1962	25	B2	0.05600	Z2B	6	31	98	460
01-360	F	1911		01	1928	34	1962	0	G6	0.01400	Z8	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
01-361	F	1907	1976	01	1924	20	1974	1	B6	0.01323	Z2B	0	2	4	26
01-362	F	1906		01	1923	5	1962	0	G6	0.05700	Z2	0	0	0	0
01-363	F	1888	1978	01	1918	260	1962	7	G6	0.05700	Z2	2	17	29	253
01-364	F	1911		07	1927	440	1964	6	G6	0.01140	Z8	1	1	21	[illegible]3
01-365	F	1901		01	1924	40	1962	10	G6	0.05700	Z2	3	15	40	[illegible]
01-367	F	1899		01	1920	221	1976	4	B6	0.01024	Z2B	1	9	20	135
01-368	M	1925		06	1947	65	1979	35	B1	0.0	Z9B	8	0	66	0
01-369	F	1906		01	1923	33	1975	0	B6	0.01043	Z2	0	0	0	0
01-370	F	1904		01	1927	21	1962	0	G6	0.01500	Z8	0	0	0	0
01-371	F	1912		07	1928	39	1979	3	B3	0.00180	Z8	1	1	13	12
01-372	F	1911	1975	01	1927	1	1962	7	G6	0.01470	Z8	2	2	24	28
01-373	F	1910		01	1927	84	1962	2	G6	0.01400	Z8	1	0	7	7
01-374	F	1910		01	1927	+0	1962	12	G6	0.01470	Z8	3	3	45	47
01-376	F	1907	1973	01	1927	33	1963	2	G6	0.01300	Z8	1	1	7	8
01-377	F	1915		07	1929	208	1979	1	B6	0.0	Z9B	0	0	4	0
01-378	F	1907		01	1925	94	1981	2	C6	0.00141	Z8B	1	1	8	9
01-379	F	1909	1981	01	1926	7	1975	18	B2	0.00281	Z8B	5	6	79	88
01-380	F	1910	1980	01	1927	3	1972	0	B6	0.00420	Z8B	0	0	0	0
01-381	M	1887	1978	02	1927	1	1964	5	G6	0.01400	Z5	1	2	13	18
01-382	F	1900		01	1920	320	1963	43	G4	0.01000	Z2	12	15	181	221
01-383	F	1907		01	1923	2	1976	0	B6	0.01006	Z2B	0	0	0	0
01-384	F	1905		01	1923	1	1975	0	B6	0.01177	Z2	0	0	0	0
01-385	F	1906	1971	01	1924	11	1963	5	G6	0.05000	Z2	1	8	18	114
01-386	F	1904		01	1927	15	1963	9	G4	0.01300	Z8	2	2	34	35
01-388	F	1873	1944	02	1928	+0	1965	2580	A1	0.01027	A1	434	401	2886	5555
01-389	F	1910	1930	01	1923	26	1963	1029	A1	0.06812	A1	111	946	435	9072
01-390	F	1887	1931	02	1925	260	1965	7400	A1	0.02527	A1	519	1180	1358	6351
01-391	F	1914	1969	07	1950	520	1964	1	B6	0.0	Z9B	0	0	1	0
01-392	M	1913	1972	07	1950	520	1964	1	B6	0.0	Z9B	0	0	1	0
01-393	M	1937		07	1950	520	1972	2	B6	0.0	Z9B	0	0	2	0
01-394	F	1944		07	1950	520	1982	0	B6	0.0	Z9C	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
01-395	F	1945		07	1950	520	1972	5	B3	0.0	Z9B	1	0	8	0
01-396	M	1947		07	1950	520	1982	0	B6	0.0	Z9B	0	0	0	0
01-397	F	1950		07	1950	498	1973	4	B3	0.0	Z9B	1	0	7	0
01-398	M	1951		07	1951	429	1982	0	B6	0.0	Z9C	0	0	0	0
01-399	F	1953		07	1953	350	1982	1	B6	0.0	Z9C	0	0	1	0
01-400	M	1903	1982	07	1961	156	1964	2	B6	0.0	Z9B	0	0	0	0
01-401	F	1910		07	1961	156	1964	3	B6	0.0	Z9B	0	0	1	0
01-402	F	1898		01	1920	18	1963	0	G6	0.05000	Z2	0	0	0	0
01-403	F	1912		02	1926	+0	1971	27	B2	0.01838	C3	8	34	118	516
01-404	M	1875	1945	67	1912	1716	1965	2800	A1	0.0	Z9A	330	0	1523	0
01-405	F	1885	1957	67	1912	1716	1965	52	A1	0.0	Z9A	11	0	106	0
01-406	M	1902	1969	67	1916	260	1963	18	B2	0.0	Z9B	5	0	51	0
01-407	M	1912	1977	67	1930	416	1963	38	B2	0.0	Z9B	9	0	78	0
01-408	F	1918		06	1934	416	1978	14	B1	0.0	Z9B	4	0	49	0
01-409	F	1914		06	1930	13	1975	34	B3	0.0	Z9B	10	0	140	0
01-410	F	1920		06	1940	156	1978	33	B1	0.0	Z9B	9	0	104	0
01-411	M	1915	1978	06	1935	200	1973	8	B2	0.0	Z9C	2	0	18	0
01-412	M	1915	1970	02	1929	+0	1963	1	D6	0.01600	Z5D	0	0	2	3
01-413	F	1901	1965	01	1924	229	1964	11	G4	0.04400	Z2	3	15	35	222
01-414	F	1897		06	1931	78	1979	2	C6	0.0	Z9B	1	0	9	0
01-415	M	1898	1980	06	1921	520	1964	0	B6	0.0	Z9B	0	0	0	0
01-416	F	1908		01	1924	2	1963	9	G6	0.04900	Z2	2	14	37	203
01-417	F	1907		01	1923	1	1963	0	G6	0.05000	Z2	0	0	0	0
01-418	M	1900	1972	06	1919	104	1963	6	G6	0.0	Z9	2	0	17	0
01-419	M	1895	1965	06	1916	260	1963	9	G6	0.0	Z9	3	0	24	0
01-420	F	1903	1967	06	1920	65	1963	2	G6	0.0	Z9	1	0	7	0
01-421	F	1887	1976	06	1915	312	1963	8	G6	0.0	Z9	2	0	35	0
01-423	M	1897		06	1919	260	1973	22	B2	0.0	Z9B	7	0	77	0
01-424	F	1882	1979	05	1924	+0	1979	350	A2	0.0	Z9A	112	0	1643	0
01-425	M	1933		07	1961	104	1964	0	B6	0.0	Z9B	0	0	0	0
01-426	F	1930		07	1961	104	1964	5	B3	0.0	Z9B	0	0	2	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
01-427	F	1960		07	1961	104	1964	5	E4	0.0	Z9	0	0	2	0
01-428	F	1957		07	1961	104	1964	2	E6	0.0	Z9	0	0	1	0
01-429	F	1897		06	1922	208	1979	1	B6	0.0	Z9B	0	0	5	0
01-430	M	1880	1969	02	1930	+0	1966	41	B2	0.02195	B3	11	18	88	197
01-431	F	1901	1975	05	1922	52	1971	765	B1	0.0	Z9B	229	0	3262	0
01-432	M	1895	1973	06	1915	520	1964	17	B2	0.0	Z9B	5	0	49	0
01-434	M	1880	1932	02	1927	156	1965	6126	A1	0.02189	A1	456	828	865	3250
01-435	F	1907		01	1925	5	1977	0	B6	0.00228	Z9B	0	0	0	0
01-436	F	1895	1976	01	1927	180	1964	8	G6	0.01140	Z8	2	2	27	25
01-437	F	1910	1971	06	1931	104	1965	1	B6	0.0	Z9B	0	0	3	0
01-438	M	1867	1940	02	1925	208	1965	1850	A1	0.01372	A1	279	382	1163	3571
01-439	F	1880	1953	04	1922	8	1968	406	A2	0.0	Z9F	96	0	971	0
01-440	F	1908		01	1924	204	1965	0	G6	0.03900	Z2	0	0	0	0
01-443	F	1911		01	1927	74	1978	8	G6	0.00200	Z8	2	2	36	33
01-447	F	1909		17	1925	110	1965	3	G6	0.01000	Z8	1	1	12	14
01-448	F	1907		01	1925	5	1964	25	G4	0.01140	Z8	7	9	102	131
01-449	F	1899		01	1922	2	1965	7	G6	0.03900	Z2	2	14	31	215
01-450	M	1877	1936	06	1912	364	1966	0	A6	0.0	Z9A	0	0	0	0
01-451	F	1908	1978	01	1924	4	1977	14	G4	0.00907	Z2	4	25	64	375
01-453	F	1899	1963	01	1920	20	1979	4	F4	0.00780	Z2	1	11	14	168
01-454	F	1880	1970	01	1920	884	1974	1990	A1	0.00034	F2	586	96	7760	1442
01-456	M	1878	1948	02	1928	26	1965	74	A1	0.03648	A3	14	44	75	454
01-457	F	1904		06	1920	78	1964	8	G4	0.0	Z9	2	0	36	0
01-459	M	1886	1971	06	1921	52	1964	10	G6	0.0	Z9	3	0	27	0
01-460	M	1882	1966	06	1912	104	1964	0	G6	0.0	Z9	0	0	0	0
01-461	M	1914	1970	06	1930	26	1964	9	G4	0.0	Z9	2	0	19	0
01-464	F	1908		01	1927	4	1970	4	G6	0.00540	Z8	1	1	17	17
01-466	F	1902	1946	01	1920	52	1965	0	A6	0.03800	Z2A	0	0	0	0
01-468	F	1910		01	1927	0	1978	0	C6	0.00209	Z8	0	0	0	0
01-469	M	1894		06	1918	52	1965	4	G6	0.0	Z9	1	0	14	0
01-470	F	1912		01	1927	70	1965	0	G6	0.01000	Z8	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
01-472	F	1896	1969	06	1919	156	1965	7	G6	0.0	Z9	2	0	27	0
01-474	F	1904		07	1921	100	1979	0	B6	0.00637	Z28	0	0	0	0
01-475	F	1901		01	1928	4	1974	0	B6	0.00330	Z8B	0	0	0	0
01-476	F	1909	1981	07	1927	71	1972	4	B3	0.00420	Z8B	1	1	16	16
01-477	F	1897	1978	02	1925	+0	1965	1240	B1	0.00475	B2	336	207	4814	3111
01-478	F	1914		01	1935	24	1965	0	G6	0.0	Z9	0	0	0	0
01-479	F	1914		01	1927	1	1978	2	C6	0.00209	Z8	1	1	11	11
01-480	F	1915		01	1927	1	1965	38	G6	0.01000	Z8	10	10	149	153
01-481	F	1909		01	1927	14	1965	0	G6	0.01000	Z8	0	0	0	0
01-482	F	1912		01	1927	6	1979	1	B6	0.00181	Z8B	0	0	5	5
01-483	M	1907		17	1922	104	1975	0	B6	0.01184	Z2B	0	0	0	0
01-484	F	1908	1974	01	1926	0	1965	0	G6	0.01000	Z8	0	0	0	0
01-485	M	1870	1951	05	1911	1300	1965	340	A1	0.0	Z9A	74	0	488	0
01-486	F	1907		01	1923	6	1974	0	B6	0.01318	Z2B	0	0	0	0
01-487	F	1911		07	1927	565	1976	0	B6	0.00257	Z8B	0	0	0	0
01-489	F	1910		01	1926	348	1965	225	G6	0.01000	Z8	57	42	828	637
01-490	F	1908		01	1924	17	1974	2	B6	0.01318	Z2B	1	3	9	52
01-491	F	1922	1966	01	1943	728	1963	7	G6	0.0	Z9	1	0	7	0
01-492	F	1900		06	1921	260	1973	1	B6	0.0	Z9B	0	0	5	0
01-493	M	1893	1975	06	1927	1820	1973	4	B3	0.0	Z9C	1	0	6	0
01-494	M	1906	1966	06	1926	999	1966	0	G6	0.0	Z9	0	0	0	0
01-495	F	1908		01	1924	4	1965	0	G6	0.03900	Z2	0	0	0	0
01-496	F	1918		07	1934	106	1966	3	G6	0.0	Z9	1	0	10	0
01-497	F	1902	1978	01	1921	8	1966	13	G6	0.03400	Z2	4	30	56	451
01-498	F	1897	1982	06	1920	104	1981	0	C6	0.0	Z9C	0	0	0	0
01-501	M	1867	1937	02	1926	156	1966	2500	A1	0.00760	A1	320	260	1102	2149
01-503	M	1936		08	1936	39	1966	0	B6	0.0	Z9B	0	0	0	0
01-504	F	1913		01	1927	2	1975	0	B6	0.0	Z9B	0	0	0	0
01-505	F	1902		01	1927	1	1966	9	G4	0.00880	Z8	2	2	36	37
01-506	F	1897		04	1923	4	1966	7	B3	0.0	Z9C	2	0	31	0
01-507	F	1909		01	1927	22	1982	6	B2	0.00119	Z8C	2	2	27	26

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
01-508	F	1906	1968	01	1944	52	1966	30	G6	0.0	Z9	6	0	50	0
01-509	F	1943		08	1943	39	1967	0	B6	0.0	Z9B	0	0	0	0
01-510	F	1897		01	1927	12	1966	38	G6	0.00880	Z8	10	10	151	152
01-511	F	1908		07	1927	9	1979	0	B6	0.00181	Z8B	0	0	0	0
01-512	F	1895	1976	04	1912	13	1973	0	B6	0.0	Z9B	0	0	0	0
01-514	F	1904		07	1924	2184	1981	2	C6	0.00097	Z5C	0	0	4	0
01-515	F	1886	1980	05	1940	0	1966	4	G6	0.0	Z9	1	0	10	0
01-516	F	1907	1976	01	1927	2	1967	7	G6	0.00780	Z8	2	2	26	29
01-518	M	1912		05	1949	+0	1977	0	B6	0.0	Z9B	0	0	0	0
01-519	M	1919		06	1937	260	1967	13	G6	0.0	Z9	3	0	26	0
01-520	F	1882	1969	02	1930	+0	1967	670	B1	0.00492	B2	174	77	2044	1158
01-525	M	1923		06	1943	104	1968	17	G6	0.0	Z9	4	0	30	0
01-526	M	1921		06	1945	38	1979	29	B1	0.0	Z9B	7	0	59	0
01-529	M	1920		06	1943	260	1975	14	B2	0.0	Z9B	3	0	26	0
01-530	M	1920	1971	06	1943	104	1968	52	B1	0.0	Z9B	11	0	71	0
01-531	M	1918		06	1941	354	1974	13	B2	0.0	Z9B	3	0	25	0
01-533	F	1903	1978	04	1911	+0	1969	4	G6	0.0	Z9	1	0	22	0
01-534	M	1920		06	1944	154	1976	1	B6	0.0	Z9B	0	0	2	0
01-536	M	1916		06	1943	286	1968	17	G6	0.0	Z9	3	0	28	0
01-537	M	1917	1971	06	1944	208	1968	59	B1	0.0	Z9B	12	0	74	0
01-540	M	1890	1981	07	1940	260	1968	0	G6	0.0	Z9	0	0	0	0
01-543	M	1920	1976	06	1943	167	1975	19	B2	0.0	Z9B	4	0	32	0
01-544	F	1879	1953	02	1930	+0	1968	93	A1	0.00430	A3	19	8	158	121
01-546	F	1897	1980	01	1914	52	1967	0	G6	0.0	Z9	0	0	0	0
01-547	F	1897		67	1920	104	1979	4	B3	0.0	Z9B	1	0	21	0
01-548	M	1917		02	1930	+0	1972	5	B3	0.00200	Z5B	1	0	14	5
01-552	M	1907		06	1936	104	1967	20	G4	0.0	Z9	5	0	44	0
01-553	F	1910		01	1948	988	1967	0	G6	0.0	Z9	0	0	0	0
01-554	F	1928		01	1952	780	1967	490	G4	0.0	Z9	38	0	323	0
01-555	F	1894		01	1921	2	1975	0	B6	0.01155	Z2B	0	0	0	0
01-556	F	1910		01	1927	0	1967	0	G6	0.00780	Z8	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
01-557	F	1908		01	1925	35	1975	2	B6	0.00293	Z8B	1	1	9	11
01-558	M	1913		02	1927	130	1981	292	C2	0.00042	B2C	91	23	955	250
01-562	F	1901	1931	01	1920	52	1970	10300	A1	0.00032	F1	1392	185	7143	2251
01-565	F	1892	1957	05	1925	26	1970	1600	A2	0.0	Z9A	385	0	3946	0
01-567	M	1885	1949	02	1925	+0	1970	1100	A2	0.00400	A2	229	218	1400	2282
01-568	M	1907	1928	05	1927	+0	1969	4900	A1	0.0	Z9A	237	0	270	0
01-569	F	1896	1980	07	1922	282	1978	4	G6	0.00804	Z2	1	6	19	97
01-570	F	1908		01	1926	260	1968	10	G4	0.0	Z9	3	0	39	0
01-571	F	1911		01	1928	44	1979	0	B6	0.00181	Z8B	0	0	0	0
01-573	F	1892	1945	01	1916	312	1970	670	A1	0.00195	F3	145	135	1307	2000
01-574	F	1885	1937	05	1924	77	1968	2730	A1	0.0	Z9A	400	0	2255	0
01-575	M	1910	1977	01	1950	1196	1973	2	B6	0.0	Z9B	0	0	1	0
01-576	F	1930		01	1946	780	1968	160	B1	0.0	Z9B	25	0	240	0
01-578	F	1904	1930	05	1926	17	1969	3700	A2	0.0	Z9A	296	0	836	0
01-579	F	1928	1928	08	1928	26	1973	2	A1	0.00289	Z2A	0	0	1	0
01-580	F	1894		01	1918	52	1972	1	B6	0.0	Z9B	0	0	5	0
01-581	M	1918		06	1946	52	1968	10	G4	0.0	Z9	2	0	16	0
01-582	F	1893		06	1917	24	1979	1	B6	0.0	Z9B	0	0	6	0
01-583	M	1890	1969	06	1918	104	1968	0	G6	0.00250	Z7	0	0	0	0
01-584	F	1908	1975	01	1926	260	1968	10	B2	0.0	Z9B	3	0	35	0
01-585	F	1906	1969	01	1925	26	1968	0	B6	0.00450	Z5B	0	0	0	0
01-586	F	1879	1973	05	1924	+0	1968	130	G6	0.0	Z9	37	0	504	0
01-588	F	1908		01	1929	104	1968	5	G6	0.0	Z9	1	0	19	0
01-589	M	1907		06	1927	78	1978	1	B6	0.0	Z9	0	0	3	0
01-590	M	1929		08	1929	39	1976	0	B6	0.01062	Z2C	0	0	0	0
01-591	F	1891	1975	01	1918	52	1973	0	G6	0.00016	Z7	0	0	0	0
01-592	F	1903	1971	01	1917	6	1968	0	G6	0.0	Z9	0	0	0	0
01-594	M	1926		01	1962	34	1975	2	B6	0.0	Z9B	0	0	2	0
01-595	F	1897		01	1917	130	1969	5	G6	0.0	Z9	2	0	25	0
01-597	F	1923		01	1940	364	1982	0	B6	0.0	Z9C	0	0	0	0
01-598	M	1879	1953	06	1941	572	1952	400	G6	0.0	Z9	27	0	71	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
01-599	F	1909		01	1927	7	1978	0	B6	0.00203	Z8B	0	0	0	0
01-601	F	1902		01	1918	6	1969	0	G6	0.00020	Z7	0	0	0	0
01-603	F	1894		01	1915	676	1968	7	G6	0.00450	Z5	2	3	33	41
01-604	F	1896		01	1914	52	1971	1	B6	0.0	Z9B	0	0	5	0
01-607	F	1907		07	1927	+0	1978	0	C6	0.00203	Z8	0	0	0	0
01-608	F	1906	1976	01	1927	11	1974	0	G6	0.00330	Z8B	0	0	0	0
01-609	F	1906		01	1926	366	1978	1	B6	0.0	Z9B	0	0	4	0
01-610	M	1904	1969	06	1919	208	1968	10	G6	0.00450	Z7	3	4	28	43
01-612	F	1859	1936	17	1923	255	1972	18	A1	0.00680	Z4A	2	5	13	57
01-613	F	1906	1936	17	1923	265	1972	658	A1	0.00680	F2	88	165	450	1987
01-614	M	1882	1922	06	1920	+0	1974	24	A2	0.0	Z9	1	0	2	0
01-617	M	1922		08	1922	39	1973	1	B6	0.00020	Z3B	0	0	3	0
01-619	F	1909	1978	01	1927	52	1969	0	G6	0.0	Z9	0	0	0	0
01-621	F	1908		01	1924	2	1978	8	B2	0.00791	Z2C	3	14	39	214
01-625	F	1911	1982	01	1927	468	1968	6	G6	0.0	Z9	2	0	21	0
01-626	F	1932		08	1932	39	1971	0	B6	0.0	Z9B	0	0	0	0
01-627	F	1897		01	1917	52	1970	0	G6	0.0	Z9	0	0	0	0
01-628	F	1908		01	1925	312	1975	0	B6	0.00200	Z5B	0	0	0	0
01-629	F	1892	1977	01	1926	260	1969	12	G6	0.0	Z9	3	0	44	0
01-633	F	1878	1926	05	1925	4	1970	2600	A2	0.0	Z9A	101	0	130	0
01-635	M	1880	1937	06	1918	312	1973	1900	A1	0.0	Z9A	318	0	1509	0
01-636	F	1879	1930	01	1919	1	1979	1	A6	0.00075	Z7	0	0	1	1
01-640	F	1908		01	1924	21	1969	34	G6	0.00420	Z5	10	10	150	143
01-653	F	1910		01	1925	78	1969	7	G6	0.00420	Z5	2	2	30	25
01-659	F	1912		01	1928	26	1969	11	G6	0.0	Z9	3	0	44	0
01-660	F	1881	1957	02	1932	+0	1970	15	A6	0.0	Z9A	3	0	28	0
01-661	M	1874	1934	06	1914	572	1974	2	A6	0.0	Z9	0	0	1	0
01-663	M	1927		08	1927	39	1969	11	G4	0.0	Z9	3	0	32	0
01-665	M	1923		08	1923	39	1969	0	G6	0.0	Z9	0	0	0	0
01-667	F	1918		01	1941	234	1972	0	B6	0.0	Z9B	0	0	0	0
01-668	M	1933		07	1964	+0	1974	1	B6	0.0	Z9	0	0	1	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
01-669	F	1917		01	1934	130	1980	0	B6	0.0	Z9C	0	0	0	0
01-670	M	1897		04	1928	+0	1969	0	G6	0.0	Z9	0	0	0	0
01-671	F	1923		01	1941	260	1972	2	B6	0.0	Z9B	0	0	5	0
01-674	M	1908		01	1931	1716	1980	1	C6	0.0	Z9C	0	0	1	0
01-681	F	1904	1978	07	1920	4	1972	0	G6	0.00320	Z7	0	0	0	0
01-684	F	1894	1974	01	1917	1	1973	0	G6	0.0	Z9	0	0	0	0
01-688	M	1868	1948	07	1920	+0	1972	0	A6	0.00320	Z7A	0	0	0	0
01-690	M	1878	1940	04	1918	+0	1970	21	A1	0.0	Z9A	4	0	24	0
01-691	F	1913	1974	04	1935	0	1971	0	B6	0.0	Z9B	0	0	0	0
01-692	M	1885	1974	02	1925	+0	1970	30	G6	0.00680	Z5	9	14	84	150
01-694	M	1886	1953	54	1928	+0	1971	10000	F4	0.0	Z9	2123	0	13346	0
01-701	M	1892	1974	06	1916	312	1970	0	G6	0.0	Z9	0	0	0	0
01-706	F	1908		07	1923	100	1980	1	C6	0.00629	Z2C	0	2	6	36
01-707	F	1908	1974	01	1927	1	1971	0	G6	0.00470	Z8	0	0	0	0
01-710	F	1901		01	1925	289	1978	0	B6	0.00141	Z5	0	0	0	0
01-711	F	1905	1982	01	1925	312	1970	0	G6	0.00370	Z5	0	0	0	0
01-715	F	1907		01	1927	5	1976	0	B6	0.00258	Z8B	0	0	0	0
01-717	M	1910		27	1927	13	1979	3	B3	0.00230	Z5	1	1	10	13
01-727	F	1908		01	1920	1	1982	4	C6	0.00092	Z7	1	2	22	36
01-728	F	1912		01	1927	6	1978	0	B6	0.00203	Z8B	0	0	0	0
01-731	F	1905		71	1926	8	1979	3	G6	0.00200	Z8	1	1	14	18
01-733	F	1911		01	1927	61	1978	45	C6	0.00200	Z8	14	13	202	190
01-736	F	1907	1931	01	1923	52	1977	1	F6	0.00170	Z7F	0	0	0	1
01-739	F	1856	1928	05	1926	7	1972	11500	A1	0.0	Z9A	645	0	1226	0
03-005	M	1917	1978	07	1948	+0	1973	0	B6	0.0	Z9C	0	0	0	0
03-008	F	1934		08	1934	39	1971	0	B6	0.0	Z9C	0	0	0	0
03-009	F	1918		01	1941	104	1972	1	B6	0.0	Z9C	0	0	2	0
03-101	F	1908	1971	05	1931	15	1963	1580	C2	0.0	Z9	380	0	4523	0
03-102	M	1908	1976	05	1931	15	1973	628	B1	0.0	Z9C	174	0	1598	0
03-103	F	1868	1952	05	1931	15	1951	420	E4	0.0	Z9	79	0	621	0
03-104	F	1880	1945	05	1931	15	1931	13900	E4	0.0	Z9	449	0	2727	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
03-105	M	1903	1957	05	1931	16	1951	2600	E4	0.0	Z9	490	0	3143	0
03-106	F	1876	1959	05	1931	16	1931	4600	B2	0.0	Z9	147	0	1388	0
03-107	F	1884	1957	05	1931	16	1931	3600	B2	0.0	Z9	115	0	1036	0
03-108	F	1875	1953	05	1931	16	1932	1900	E4	0.0	Z9	82	0	660	0
03-109	F	1904	1957	05	1931	18	1953	630	B2	0.0	Z9	125	0	1120	0
03-110	F	1899	1967	05	1931	20	1964	584	B1	0.0	Z9	143	0	1583	0
03-111	F	1909		05	1931	20	1973	879	B2	0.0	Z9C	244	0	3440	0
03-112	F	1899	1968	05	1931	26	1960	5310	B1	0.0	Z9	1212	0	13669	0
03-113	F	1914	1946	05	1931	38	1932	7800	E4	0.0	Z9	336	0	2115	0
03-114	F	1901	1968	05	1931	36	1964	949	B1	0.0	Z9	231	0	2606	0
03-115	F	1911		05	1931	26	1973	745	B1	0.0	Z9C	206	0	2911	0
03-116	F	1907	1983	05	1931	25	1983	931	A1	0.0	Z9	289	0	4069	0
03-117	M	1898	1957	05	1931	45	1953	1540	B2	0.0	Z9	303	0	1931	0
03-118	F	1898	1955	05	1931	41	1953	3090	B2	0.0	Z9	608	0	5159	0
03-119	F	1880	1960	05	1931	7	1959	1038	C2	0.0	Z9	233	0	2256	0
03-120	F	1879	1937	05	1931	11	1931	5300	E4	0.0	Z9	171	0	622	0
03-121	F	1911	1972	05	1931	9	1964	371	B1	0.0	Z9	91	0	1099	0
03-122	M	1907	1981	05	1931	10	1931	6500	E4	0.0	Z9	92	0	904	0
03-123	M	1914	1937	05	1931	9	1931	9700	B2	0.0	Z9	139	0	361	0
03-124	M	1910	1983	05	1931	9	1981	235	C2	0.0	Z9C	71	0	720	0
03-125	F	1913	1976	05	1931	11	1973	556	B1	0.0	Z9C	154	0	1983	0
03-126	F	1910	1965	05	1931	20	1965	1300	C2	0.0	Z9	323	0	3449	0
03-127	F	1908		05	1931	26	1962	565	C2	0.0	Z9	134	0	1883	0
03-135	M	1905	1983	05	1931	+0	1973	1431	B1	0.0	Z9C	398	0	4020	0
03-139	M	1908		05	1933	11	1973	373	C2	0.0	Z9C	101	0	993	0
03-140	M	1905	1937	05	1933	11	1961	500	F4	0.0	Z9	40	0	82	0
03-141	M	1906	1963	05	1933	11	1962	961	C2	0.0	Z9	220	0	1550	0
03-201	F	1909	1963	04	1922	+0	1962	2968	C2	0.0	Z9	805	0	9741	0
03-202	M	1895		05	1925	+0	1960	1800	G4	0.0	Z9	455	0	4941	0
03-203	F	1903	1973	05	1933	+0	1959	84	C2	0.0	Z9	18	0	217	0
03-204	F	1896	1970	04	1922	+0	1960	21	C2	0.0	Z9	6	0	74	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
03-205	F	1900	1979	05	1929	15	1968	291	C2	0.0	Z9	78	0	1069	0
03-206	M	1914	1975	05	1936	4	1973	3297	B1	0.0	Z9C	858	0	7176	0
03-207	F	1879	1969	04	1922	416	1960	755	C2	0.0	Z9	188	0	2344	0
03-209	M	1894	1960	05	1925	572	1973	1105	A1	0.0	Z9A	254	0	1776	0
03-210	M	1906	1958	05	1926	+0	1957	1350	C2	0.00089	F2	321	12	2360	132
03-211	M	1890		05	1923	20	1960	10	C3	0.0	Z9	3	0	29	0
03-212	F	1902	1951	04	1927	+0	1951	1300	B2	0.00130	F1	270	7	2317	95
03-213	F	1892	1955	05	1925	+0	1952	6570	B2	0.0	Z9	1452	0	14358	0
03-214	F	1895	1966	05	1925	+0	1964	1382	C2	0.0	Z9F	370	0	4477	0
03-215	M	1896	1971	05	1925	+0	1961	3630	C2	0.0	Z9	932	0	8685	0
03-216	F	1907	1961	05	1922	+0	1961	530	C2	0.0	Z9F	142	0	1662	0
03-217	M	1912	1974	05	1921	+0	1963	460	C2	0.0	Z9	128	0	1308	0
03-218	M	1908		05	1924	+0	1972	3	B3	0.0	Z9C	1	0	11	0
03-219	F	1888	1961	04	1919	+0	1951	60	B2	0.0	Z9	14	0	178	0
03-220	M	1920	1983	04	1928	208	1976	130	B1	0.0	Z9C	38	0	386	0
03-221	M	1908	1963	05	1924	+0	1957	620	C2	0.0	Z9	152	0	1273	0
03-222	M	1872	1954	05	1922	+0	1951	1600	B2	0.0	Z9	367	0	2702	0
03-223	F	1886	1968	05	1929	156	1951	4200	B2	0.0	Z9	804	0	9181	0
03-224	M	1869	1960	54	1922	364	1951	5400	B2	0.0	Z9	1155	0	8929	0
03-225	M	1922		04	1929	+0	1980	28	C2	0.0	Z9C	8	0	88	0
03-226	M	1874	1953	05	1934	39	1951	10700	B2	0.0	Z9	1837	0	9588	0
03-227	F	1878	1952	05	1930	+0	1952	1000	B2	0.0	Z9	199	0	1612	0
03-228	M	1900	1955	05	1927	+0	1951	5600	B2	0.0	Z9	1164	0	7866	0
03-230	F	1899	1982	05	1927	+0	1976	438	B1	0.0	Z9C	132	0	1934	0
03-231	F	1879	1973	05	1939	+0	1952	60	E4	0.0	Z9	9	0	97	0
03-232	F	1898	1957	05	1917	+0	1956	4700	D2	0.0	Z9	1257	0	14981	0
03-233	F	1879	1947	05	1922	+0	1947	4000	C4	0.0	Z9	849	0	7473	0
03-234	F	1890	1965	05	1915	+0	1965	920	C2	0.0	Z9	280	0	3861	0
03-235	F	1900	1968	05	1928	+0	1965	1290	C2	0.0	Z9	336	0	4001	0
03-236	F	1880	1961	05	1927	+0	1951	500	B2	0.0	Z9	104	0	1114	0
03-237	F	1890		04	1923	156	1961	3	C6	0.0	Z9	1	0	12	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
03-238	M	1883	1954	05	1926	+0	1951	13900	B2	0.0	Z9	2951	0	19944	0
03-239	F	1883	1953	05	1925	+0	1970	10000	A1	0.0	Z9A	2252	0	21306	0
03-240	F	1916	1955	05	1930	+0	1973	4320	A1	0.0	Z9A	917	0	8071	0
03-401	F	1900	1963	01	1923	95	1960	2287	C2	0.0	Z9	588	0	6896	0
03-402	F	1905	1982	01	1923	260	1974	1223	B1	0.00008	F1	370	12	5595	185
03-403	F	1915	1964	01	1935	572	1957	8	C3	0.0	Z9	1	0	11	0
03-404	F	1897		01	1923	195	1975	577	B1	0.0	Z9C	177	0	2698	0
03-405	F	1904		16	1924	273	1962	625	C2	0.0	Z9	159	0	2368	0
03-406	F	1914		01	1935	484	1980	3	C6	0.0	Z9C	1	0	12	0
03-407	F	1905	1961	01	1923	1196	1958	1545	B1	0.00019	F6	382	4	4286	64
03-408	F	1908	1959	01	1924	676	1957	160	C2	0.0	Z9	39	0	414	0
03-409	F	1923		01	1942	78	1972	8	B2	0.0	Z9C	2	0	23	0
03-410	F	1895	1974	01	1923	104	1957	60	C2	0.0	Z9	15	0	203	0
03-411	F	1908		01	1931	572	1976	1	B3	0.0	Z9C	0	0	5	0
03-412	F	1894	1983	01	1922	134	1977	227	B2	0.0	Z9C	72	0	1112	0
03-413	F	1917	1978	01	1939	169	1972	4	B3	0.0	Z9C	1	0	10	0
03-414	F	1921		01	1946	557	1972	3	B6	0.0	Z9C	1	0	6	0
03-415	F	1911	1973	01	1930	780	1957	15	C3	0.0	Z9	3	0	30	0
03-416	F	1907	1983	01	1923	65	1981	1097	C2	0.0	Z9B	359	0	5534	0
03-417	F	1909	1966	01	1924	60	1964	617	C2	0.0	Z9	166	0	2023	0
03-418	F	1896	1980	61	1926	602	1972	5	B3	0.0	Z9C	1	0	17	0
03-419	F	1906		01	1924	208	1962	679	C2	0.0	Z9	177	0	2685	0
03-420	F	1906	1960	01	1922	212	1957	18	C2	0.0	Z9	4	0	49	0
03-421	F	1908		71	1924	117	1979	3	C3	0.0	Z9C	1	0	14	0
03-422	F	1907		06	1925	104	1981	4	C3	0.0	Z9C	1	0	20	0
03-423	F	1907	1972	01	1923	641	1962	591	C2	0.0	Z9	155	0	2064	0
03-424	F	1905		01	1923	186	1978	245	C2	0.0	Z9C	77	0	1180	0
03-425	F	1916		01	1935	293	1980	3	C6	0.0	Z9C	1	0	9	0
03-426	F	1906		01	1924	1196	1981	131	C2	0.0	Z9C	42	0	643	0
03-427	F	1906		01	1925	823	1973	12	B2	0.0	Z9C	4	0	56	0
03-428	F	1908		01	1925	164	1974	493	B1	0.0	Z9C	148	0	2230	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
03-429	F	1908	1976	01	1923	208	1974	1169	B1	0.0	Z9C	354	0	4975	0
03-430	F	1922		01	1941	468	1971	4	B3	0.0	Z9C	1	0	11	0
03-431	F	1901	1982	01	1922	156	1963	1297	C2	0.0	Z9	349	0	5337	0
03-432	F	1902		01	1923	112	1980	23	C2	0.0	Z9C	8	0	116	0
03-433	F	1904		01	1924	117	1964	1052	C2	0.0	Z9	281	0	4276	0
03-434	F	1920		01	1941	125	1975	5	B2	0.0	Z9C	1	0	14	0
03-435	F	1912		01	1934	104	1971	3	B6	0.0	Z9C	1	0	9	0
03-436	F	1910		01	1926	619	1975	8	B3	0.0	Z9C	2	0	33	0
03-437	F	1906		01	1926	52	1957	55	C2	0.0	Z9	13	0	193	0
03-438	F	1908		01	1925	8	1957	0	C6	0.0	Z9	0	0	0	0
03-439	F	1906		01	1925	56	1957	0	C6	0.0	Z9	0	0	0	0
03-440	F	1908		01	1925	3	1979	1	C6	0.0	Z9C	0	0	3	0
03-441	F	1905	1981	01	1925	528	1957	56	C2	0.0	Z9	13	0	198	0
03-442	F	1904		01	1924	13	1976	4	B2	0.0	Z9	1	0	19	0
03-443	F	1914		01	1935	268	1980	0	C6	0.0	Z9C	0	0	0	0
03-444	F	1907		01	1925	56	1980	12	C3	0.0	Z9C	4	0	59	0
03-445	F	1905	1974	01	1922	260	1966	1367	C2	0.0	Z9	380	0	5237	0
03-446	F	1903		01	1922	260	1980	56	C2	0.0	Z9C	18	0	279	0
03-447	F	1906	1981	01	1924	4	1958	2	C6	0.0	Z9	1	0	7	0
03-448	F	1903	1963	01	1924	19	1958	25	C2	0.0	Z9	6	0	73	0
03-449	F	1905	1974	01	1922	1456	1964	1135	B1	0.0	Z9	308	0	4239	0
03-450	F	1910		01	1924	697	1979	8	C3	0.0	Z9C	2	0	36	0
03-451	F	1922		01	1940	524	1982	0	B6	0.0	Z9C	0	0	0	0
03-452	F	1909		16	1925	728	1983	16	B2	0.0	Z9C	5	0	70	0
03-453	F	1907		01	1924	8	1981	3	C6	0.0	Z9C	1	0	16	0
03-454	F	1914	1982	06	1934	548	1958	48	C2	0.0	Z9	9	0	108	0
03-455	F	1906		01	1922	56	1975	491	B1	0.00059	F2	153	53	2392	799
03-456	F	1921	1965	01	1942	470	1958	33	C2	0.0	Z9	5	0	33	0
03-457	F	1915		01	1939	520	1972	1	B6	0.0	Z9C	0	0	3	0
03-458	F	1925		01	1946	1664	1982	20	B2	0.0	Z9C	3	0	26	0
03-459	F	1906	1980	01	1924	43	1976	774	B1	0.0	Z9C	239	0	3537	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
03-460	F	1905		01	1923	19	1977	4	C6	0.0	Z9C	1	0	19	0
03-461	F	1896		01	1922	6	1958	6	C3	0.0	Z9	1	0	23	0
03-462	F	1906		01	1922	2912	1981	217	C2	0.0	Z9C	71	0	1086	0
03-463	F	1918	1966	01	1942	832	1958	33	C2	0.0	Z9	3	0	18	0
03-464	F	1907		01	1923	104	1974	0	C6	0.0	Z9C	0	0	2	0
03-465	F	1908		01	1925	8	1981	0	C6	0.0	Z9C	0	0	2	0
03-466	F	1904		01	1924	10	1981	3	C6	0.0	Z9C	1	0	13	0
03-467	F	1911		01	1926	416	1981	7	C3	0.0	Z9C	2	0	30	0
03-468	F	1908		01	1926	121	1958	29	C2	0.0	Z9	7	0	102	0
03-469	F	1903	1960	01	1925	30	1958	10	C3	0.0	Z9	2	0	27	0
03-470	F	1926		01	1943	247	1971	3	B3	0.0	Z9C	1	0	8	0
03-471	F	1908	1981	01	1926	91	1958	13	C3	0.0	Z9	3	0	45	0
03-472	F	1922		01	1941	247	1972	5	B3	0.0	Z9C	1	0	14	0
03-473	F	1904	1965	01	1922	156	1962	1170	C2	0.0	Z9	311	0	3793	0
03-474	F	1909		01	1925	21	1958	19	C2	0.0	Z9	5	0	70	0
03-475	F	1903	1962	01	1921	65	1958	0	C6	0.0	Z9	0	0	0	0
03-476	F	1895	1970	01	1927	6	1958	0	C6	0.0	Z9	0	0	0	0
03-477	F	1911		01	1925	11	1982	1	B6	0.0	Z9C	0	0	5	0
03-478	F	1907		01	1924	8	1958	5	C6	0.0	Z9	1	0	19	0
03-479	F	1908		01	1924	52	1981	29	C2	0.00001	F6	9	0	142	1
03-480	F	1909		01	1924	10	1980	0	C6	0.0	Z9C	0	0	0	0
03-481	F	1922		01	1942	481	1982	10	B2	0.0	Z9C	3	0	29	0
03-482	F	1927		01	1945	83	1972	3	B6	0.0	Z9C	1	0	6	0
03-483	F	1901		01	1922	177	1980	1	C6	0.0	Z9C	0	0	2	0
03-484	F	1888	1966	01	1919	156	1962	1622	C2	0.0	Z9	448	0	5807	0
03-485	F	1909	1977	01	1929	364	1958	0	C6	0.0	Z9	0	0	0	0
03-486	F	1909		01	1925	156	1977	208	B1	0.0	Z9	64	0	973	0
03-487	F	1907	1964	61	1924	676	1958	367	C2	0.00250	F6	90	12	1055	187
03-488	F	1907	1975	01	1922	26	1958	170	C2	0.00199	F6	43	7	621	101
03-489	F	1911	1964	01	1926	73	1958	120	C2	0.0	Z9	29	0	326	0
03-490	M	1904	1981	07	1925	177	1973	5	B3	0.0	Z9C	1	0	14	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
03-491	F	1908		01	1924	2	1979	19	C2	0.0	Z9C	6	0	92	0
03-492	F	1928		01	1946	325	1973	5	B3	0.0	Z9C	1	0	10	0
03-493	F	1893		01	1920	199	1980	4	C6	0.0	Z9C	1	0	21	0
03-494	F	1902	1982	01	1924	177	1959	4	C3	0.0	Z9	1	0	15	0
03-495	F	1910	1980	01	1923	7	1976	0	B6	0.0	Z9C	0	0	2	0
03-496	F	1907		01	1923	8	1981	1	C6	0.0	Z9C	0	0	4	0
03-497	F	1903	1970	01	1923	260	1959	16	C2	0.0	Z9	4	0	52	0
03-498	F	1905		67	1923	1040	1976	2	B3	0.0	Z9C	1	0	7	0
03-499	F	1905		01	1924	56	1978	185	C2	0.00175	C3	58	68	888	1019
03-500	F	1901	1959	01	1922	8	1959	0	C6	0.0	Z9	0	0	0	0
03-501	F	1912		01	1928	8	1959	7	C3	0.0	Z9	2	0	24	0
03-502	F	1887	1964	01	1918	156	1959	170	C2	0.0	Z9	46	0	585	0
03-503	F	1894	1960	01	1922	112	1959	125	C2	0.0	Z9	32	0	362	0
03-504	F	1905		01	1922	30	1981	8	C3	0.0	Z9C	3	0	41	0
03-505	F	1907	1976	01	1923	1300	1975	169	B2	0.0	Z9C	52	0	725	0
03-506	F	1917		01	1935	1872	1975	9	B2	0.0	Z9C	2	0	16	0
03-507	F	1907	1962	01	1923	6	1959	12	C3	0.0	Z9	3	0	36	0
03-508	F	1905	1963	01	1923	8	1959	10	C3	0.0	Z9	3	0	31	0
03-509	F	1907		01	1924	2548	1973	28	B1	0.0	Z9C	8	0	125	0
03-510	F	1907	1977	01	1923	2028	1962	729	C2	0.0	Z9	191	0	2719	0
03-511	F	1910	1979	01	1946	673	1959	10	C3	0.0	Z9	1	0	7	0
03-512	F	1906		01	1925	26	1959	11	C3	0.0	Z9	3	0	41	0
03-513	F	1908		01	1925	48	1974	73	B1	0.0	Z9	22	0	332	0
03-514	F	1909		01	1925	208	1959	26	C2	0.0	Z9	6	0	97	0
03-515	F	1908		01	1925	91	1983	4	B3	0.0	Z9C	1	0	19	0
03-516	F	1911		01	1925	290	1981	4	C6	0.0	Z9C	1	0	20	0
03-517	F	1922		01	1943	260	1972	1	B6	0.0	Z9C	0	0	1	0
03-518	F	1921		01	1940	464	1972	8	B3	0.0	Z9C	2	0	19	0
03-519	F	1903		01	1924	8	1959	98	C2	0.0	Z9	25	0	380	0
03-520	F	1907		01	1925	780	1974	112	C2	0.0	Z9	33	0	505	0
03-521	F	1907	1961	01	1925	39	1959	10	C3	0.0	Z9	2	0	27	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
03-522	F	1898		01	1921	52	1981	85	C2	0.0	Z9C	28	0	447	0
03-523	F	1900		01	1923	30	1980	8	C3	0.0	Z9C	2	0	38	0
03-524	F	1903		01	1925	260	1972	48	B2	0.0	Z9C	14	0	211	0
03-525	F	1911	1976	01	1931	2132	1959	19	C2	0.0	Z9	3	0	25	0
03-526	F	1896	1981	01	1925	52	1959	0	C6	0.0	Z9	0	0	0	0
03-527	F	1909		01	1925	130	1959	5	C3	0.0	Z9	1	0	19	0
03-528	F	1904		01	1922	524	1959	1630	C2	0.00326	F6	412	94	6332	1412
03-529	F	1902		01	1921	104	1980	73	C2	0.0	Z9C	24	0	376	0
03-530	F	1907	1965	01	1923	91	1963	474	C2	0.0	Z9	127	0	1541	0
03-531	F	1906		01	1925	403	1959	41	C2	0.0	Z9	10	0	153	0
03-532	F	1910		01	1926	190	1980	44	C2	0.0	Z9C	14	0	200	0
03-533	F	1908		01	1925	260	1979	12	C3	0.0	Z9C	4	0	56	0
03-534	F	1910		01	1925	104	1976	3	B3	0.0	Z9	1	0	15	0
03-535	F	1907		01	1922	21	1964	227	C2	0.0	Z9	63	0	987	0
03-536	F	1910		01	1925	7	1959	35	C2	0.0	Z9	9	0	132	0
03-537	F	1900		07	1916	52	1977	1	C6	0.0	Z9C	0	0	6	0
03-538	F	1909	1976	01	1927	13	1959	61	C2	0.0	Z9	15	0	200	0
03-539	F	1900		01	1922	20	1979	5	C3	0.0	Z9C	2	0	24	0
03-540	F	1904		01	1923	364	1973	1605	B1	0.0	Z9C	481	0	7348	0
03-541	F	1913		01	1935	178	1978	0	C6	0.0	Z9C	0	0	0	0
03-542	F	1904		01	1922	13	1981	22	C2	0.0	Z9C	7	0	114	0
03-543	F	1918		01	1947	117	1982	0	B6	0.0	Z9C	0	0	1	0
03-544	F	1906	1975	01	1922	26	1959	5	C3	0.0	Z9	1	0	19	0
03-545	F	1898	1981	01	1920	208	1959	0	C6	0.0	Z9	0	0	0	0
03-546	F	1903	1981	01	1925	52	1959	95	C2	0.0	Z9	23	0	347	0
03-547	F	1907	1962	01	1923	108	1959	19	C2	0.00310	F3	5	1	55	16
03-548	F	1906		01	1922	17	1971	80	B1	0.0	Z9C	24	0	377	0
03-549	F	1910		01	1925	936	1980	41	C2	0.0	Z9C	13	0	198	0
03-550	F	1900		01	1917	104	1980	8	C3	0.0	Z9C	3	0	46	0
03-551	F	1903		01	1922	338	1973	1077	C2	0.0	Z9C	324	0	4984	0
03-552	F	1904		01	1924	108	1978	114	C2	0.0	Z9C	36	0	545	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
03-553	F	1904		01	1924	13	1979	6	C6	0.0	Z9C	2	0	31	0
03-554	F	1899	1977	01	1924	433	1961	2000	G4	0.0	Z9	513	0	7258	0
03-555	F	1913	1978	71	1928	364	1972	2	B6	0.0	Z9C	1	0	9	0
03-556	F	1911		01	1928	100	1981	0	C6	0.0	Z9C	0	0	2	0
03-557	F	1910	1978	01	1925	3	1959	0	C6	0.0	Z9	0	0	0	0
03-558	F	1904	1971	01	1923	13	1959	115	C2	0.02173	C6	29	50	395	755
03-559	F	1907	1975	01	1922	21	1959	17	C2	0.0	Z9	4	0	63	0
03-561	F	1909		61	1924	416	1959	67	C2	0.0	Z9	17	0	254	0
03-562	F	1908	1980	01	1927	520	1972	4	B3	0.0	Z9C	1	0	13	0
03-563	F	1909		01	1924	10	1980	4	C3	0.0	Z9C	1	0	22	0
03-564	F	1906		01	1923	3	1981	2	C6	0.0	Z9C	0	0	8	0
03-565	F	1913	1979	01	1930	676	1978	7	C3	0.0	Z9C	2	0	25	0
03-566	F	1910		01	1930	624	1978	2	C6	0.0	Z9C	1	0	8	0
03-567	F	1900		01	1922	104	1972	26	B2	0.0	Z9C	8	0	120	0
03-568	F	1905	1977	01	1922	260	1959	120	C2	0.0	Z9	30	0	434	0
03-569	F	1901	1973	01	1922	312	1959	144	C2	0.0	Z9	36	0	495	0
03-570	F	1908		01	1925	43	1981	1	C6	0.0	Z9C	0	0	7	0
03-571	F	1909		01	1925	52	1981	798	C2	0.0	Z9C	257	0	3877	0
03-572	F	1906		01	1924	56	1977	62	C2	0.0	Z9C	19	0	297	0
03-573	F	1900	1979	01	1925	52	1977	16	C6	0.0	Z9C	5	0	69	0
03-574	F	1904		71	1920	624	1976	1	B6	0.0	Z9C	0	0	3	0
03-575	F	1913		01	1931	52	1973	0	B6	0.0	Z9C	0	0	0	0
03-576	F	1909		01	1925	156	1981	5	C3	0.0	Z9C	2	0	24	0
03-577	F	1901	1961	01	1921	104	1959	81	C2	0.0	Z9	21	0	247	0
03-578	F	1909	1980	01	1924	30	1976	8	B2	0.0	Z9	2	0	37	0
03-579	F	1905		01	1922	13	1959	30	C2	0.0	Z9	8	0	124	0
03-580	F	1904		01	1923	4	1959	2	C6	0.0	Z9	1	0	8	0
03-581	F	1904		01	1922	10	1959	13	C3	0.0	Z9	3	0	53	0
03-583	M	1893	1962	07	1930	+0	1959	50	C2	0.0	Z9	11	0	84	0
03-584	F	1905	1959	01	1923	+0	1959	6000	A4	0.0	Z9	1540	0	17131	0
03-585	F	1894	1982	01	1918	260	1966	74	C2	0.0	Z9	21	0	339	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
03-586	F	1908	1968	01	1926	82	1967	900	C2	0.0	Z9	245	0	2972	0
03-587	F	1906		01	1925	34	1959	13	C3	0.0	Z9	3	0	49	0
03-588	F	1901	1967	01	1922	229	1962	316	C2	0.0	Z9	83	0	1041	0
03-589	F	1906	1969	01	1924	21	1959	77	C2	0.0	Z9	19	0	249	0
03-590	F	1900	1982	01	1922	26	1965	104	C2	0.0	Z9	29	0	452	0
03-591	F	1907		17	1926	2340	1980	5	C3	0.0	Z9C	1	0	11	0
03-592	F	1905		01	1922	78	1979	70	C3	0.0	Z9	23	0	353	0
03-593	F	1905		01	1922	10	1981	12	C3	0.0	Z9C	4	0	60	0
03-594	F	1905	1968	01	1922	52	1959	41	C2	0.0	Z9	11	0	137	0
03-595	F	1902		01	1923	52	1980	0	C6	0.0	Z9C	0	0	0	0
03-596	F	1904		01	1922	8	1979	10	C3	0.0	Z9C	3	0	53	0
03-597	F	1903		16	1925	1300	1972	74	B1	0.0	Z9C	18	0	237	0
03-598	M	1890	1981	07	1933	4	1971	1	B6	0.0	Z9C	0	0	2	0
03-599	F	1906	1975	01	1922	26	1959	9	C3	0.0	Z9	2	0	33	0
03-600	F	1902		07	1926	988	1972	0	B6	0.0	Z9C	0	0	0	0
03-601	F	1893	1969	01	1925	260	1960	6	C3	0.0	Z9	2	0	19	0
03-602	F	1899	1979	01	1925	104	1960	4	C6	0.0	Z9	1	0	13	0
03-603	F	1888	1979	01	1924	520	1960	0	C6	0.0	Z9	0	0	0	0
03-604	F	1899		01	1916	572	1981	4	C6	0.0	Z9C	1	0	19	0
03-605	F	1900		01	1921	364	1972	1	B6	0.0	Z9C	0	0	3	0
03-606	F	1903		01	1924	6	1971	2	B6	0.0	Z9C	1	0	9	0
03-607	F	1906		01	1922	26	1981	91	C2	0.0	Z9C	30	0	470	0
03-608	F	1895	1976	01	1917	104	1960	19	C2	0.0	Z9	5	0	80	0
03-609	F	1896	1974	01	1923	4	1960	0	C6	0.0	Z9	0	0	0	0
03-610	F	1917		01	1935	104	1973	1	B6	0.0	Z9C	0	0	4	0
03-611	F	1893	1969	01	1916	208	1960	3	C6	0.0	Z9	1	0	12	0
03-612	F	1892	1968	01	1918	234	1960	500	C2	0.0	Z9	135	0	1806	0
03-613	F	1905		01	1925	95	1972	2	B6	0.0	Z9C	0	0	7	0
03-614	F	1909		01	1924	56	1975	94	B2	0.0	Z9	29	0	439	0
03-615	F	1905		01	1923	107	1975	14	B1	0.0	Z9	4	0	68	0
03-617	F	1902	1951	01	1921	312	1963	7000	F4	0.0	Z9	1560	0	14586	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
03-618	F	1893	1969	01	1920	43	1960	10	C3	0.0	Z9	3	0	36	0
03-619	F	1903	1962	01	1922	34	1962	1576	C3	0.00139	F1	425	74	5041	1105
03-620	F	1923		01	1942	208	1971	5	B3	0.0	Z9C	1	0	12	0
03-621	F	1916		01	1944	208	1971	4	B3	0.0	Z9C	1	0	10	0
03-622	F	1910		01	1926	104	1960	0	G6	0.0	Z9	0	0	0	0
03-623	F	1902	1978	01	1924	+0	1960	4	G6	0.0	Z9	1	0	15	0
03-624	F	1905	1959	01	1923	156	1959	1000	A4	0.0	Z9	251	0	2716	0
03-625	F	1901		01	1923	13	1981	2	C6	0.0	Z9C	1	0	11	0
03-626	F	1906		01	1924	208	1960	200	G4	0.0	Z9	51	0	768	0
03-627	F	1905	1966	01	1924	208	1960	50	G4	0.0	Z9	13	0	153	0
03-628	F	1905	1974	01	1921	34	1962	0	C6	0.0	Z9	0	0	0	0
03-629	F	1903	1969	01	1922	+0	1960	0	G6	0.0	Z9	0	0	0	0
03-630	F	1908		01	1924	17	1974	19	B1	0.0	Z9C	6	0	86	0
03-632	F	1905	1975	01	1922	+0	1960	0	G6	0.0	Z9	0	0	0	0
03-633	F	1902		01	1922	780	1960	20	G6	0.0	Z9	5	0	79	0
03-634	F	1909	1961	01	1924	+0	1960	3	G6	0.0	Z9	1	0	9	0
03-635	F	1907		01	1925	+0	1960	47	G6	0.0	Z9	12	0	181	0
03-636	F	1903		01	1924	186	1981	6	C3	0.0	Z9C	2	0	28	0
03-637	F	1906		01	1924	6	1979	39	C2	0.0	Z9C	13	0	192	0
03-638	F	1902	1972	01	1924	+0	1960	7	G6	0.0	Z9	2	0	24	0
03-639	F	1912		01	1925	156	1960	67	G4	0.0	Z9	17	0	254	0
03-640	F	1902		01	1924	60	1960	5	C3	0.0	Z9	1	0	19	0
03-641	F	1904		01	1922	26	1979	9	C3	0.0	Z9C	3	0	45	0
03-642	F	1905	1978	01	1922	52	1976	31	B2	0.0	Z9C	10	0	146	0
03-643	F	1909	1979	01	1926	156	1975	10	B2	0.0	Z9C	3	0	40	0
03-645	F	1906		01	1924	312	1959	56	C2	0.0	Z9	14	0	212	0
03-646	F	1888	1981	01	1926	+0	1960	0	G6	0.0	Z9	0	0	0	0
03-647	F	1901		01	1925	5	1960	35	G6	0.0	Z9	9	0	134	0
03-648	F	1903	1956	01	1922	155	1956	5000	B2	0.00433	F1	1216	272	12670	4068
03-649	F	1906	1954	01	1924	1352	1951	1300	B2	0.00005	F6	282	0	2725	5
03-666	F	1905	1929	01	1923	347	1978	24812	A1	0.00024	F1	2127	336	6560	2335

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
03-671	F	1906	1953	01	1922	8	1952	3820	B2	0.00433	F1	890	147	8980	2186
03-672	F	1899		01	1924	+0	1960	3	G6	0.0	Z9	1	0	12	0
03-673	F	1909		71	1926	8	1960	35	G6	0.0	Z9	9	0	131	0
03-674	F	1908	1977	01	1925	43	1976	2	B3	0.0	Z9C	1	0	9	0
03-676	F	1897	1977	01	1924	+0	1963	1700	C2	0.0	Z9	455	0	6514	0
03-677	M	1899	1965	06	1924	+0	1961	232	G4	0.0	Z9	60	0	522	0
03-678	M	1919		71	1953	988	1982	3	B3	0.0	Z9C	0	0	2	0
03-679	F	1910		01	1930	10	1977	1	B3	0.0	Z9C	0	0	6	0
03-681	F	1906		01	1922	6	1962	1	G6	0.0	Z9	0	0	3	0
03-682	F	1907		01	1925	60	1978	2	C6	0.0	Z9C	1	0	8	0
03-683	F	1906	1979	01	1923	0	1961	0	C6	0.0	Z9	0	0	0	0
03-684	F	1907		01	1927	17	1982	0	B6	0.0	Z9C	0	0	0	0
03-685	F	1902		01	1921	65	1979	86	C2	0.0	Z9C	28	0	442	0
03-686	F	1904		01	1923	1040	1983	12	C3	0.0	Z9C	4	0	59	0
03-687	F	1900	1974	01	1925	43	1961	51	C2	0.0	Z9	13	0	176	0
03-688	F	1918		01	1935	367	1972	3	B6	0.0	Z9C	1	0	8	0
03-689	F	1903		01	1923	208	1982	70	B2	0.0	Z9B	23	0	348	0
03-690	F	1909	1967	01	1924	290	1959	380	B2	0.0	Z9C	95	0	1164	0
03-692	M	1887	1976	07	1920	+0	1961	6	C3	0.0	Z9	2	0	17	0
03-693	F	1920		01	1942	520	1952	14	G6	0.0	Z9	1	0	10	0
03-695	F	1921		01	1942	44	1982	1	B3	0.0	Z9C	0	0	4	0
03-696	F	1932		01	1950	52	1963	0	C6	0.0	Z9	0	0	0	0
03-697	F	1902	1981	01	1924	34	1967	181	C2	0.0	Z9	51	0	759	0
03-701	F	1907		01	1924	9	1977	0	C6	0.0	Z9	0	0	0	0
03-703	F	1921		01	1946	282	1980	1	C6	0.0	Z9C	0	0	3	0
03-710	F	1907	1981	01	1924	728	1977	3	C6	0.0	Z9C	1	0	15	0
03-712	F	1922		01	1942	62	1977	7	C3	0.0	Z9C	2	0	21	0
03-713	F	1921		01	1941	1456	1971	2	B6	0.0	Z9C	0	0	2	0
03-714	F	1923		01	1942	364	1971	3	B3	0.0	Z9C	1	0	8	0
03-716	F	1920	1976	01	1941	104	1971	0	B6	0.0	Z9C	0	0	0	0
03-717	F	1906	1977	01	1922	156	1977	150	C6	0.0	Z9	47	0	682	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
03-720	F	1910		01	1926	52	1976	6	B2	0.0	Z9C	2	0	25	0
03-722	F	1905		01	1924	4	1977	3	B2	0.0	Z9C	1	0	13	0
03-726	F	1905	1972	01	1922	186	1968	574	C2	0.0	Z9	164	0	2206	0
03-727	F	1906	1977	01	1923	988	1972	165	B1	0.0	Z9B	49	0	696	0
03-729	F	1926		01	1943	208	1973	1	B6	0.0	Z9C	0	0	3	0
03-730	M	1894	1963	06	1923	+0	1961	7	C3	0.0	Z9	2	0	16	0
03-732	F	1924		01	1942	78	1973	2	B6	0.0	Z9C	0	0	4	0
03-736	F	1896		16	1919	22	1980	0	C6	0.0	Z9C	0	0	0	0
03-741	F	1908		01	1925	260	1975	4	B3	0.0	Z9C	1	0	16	0
03-748	F	1910		01	1927	+0	1977	5	B2	0.0	Z9C	1	0	22	0
03-752	F	1904		01	1922	15	1980	7	C3	0.0	Z9C	2	0	36	0
03-753	F	1906		01	1922	+0	1980	12	C3	0.0	Z9C	4	0	64	0
03-757	F	1902		01	1923	91	1978	10	C6	0.0	Z9C	3	0	50	0
03-761	F	1901		01	1927	1144	1980	17	C3	0.0	Z9C	5	0	60	0
03-763	F	1901		01	1931	52	1976	0	C6	0.0	Z9C	0	0	0	0
03-764	F	1908		01	1926	364	1981	1	C6	0.0	Z9C	0	0	3	0
03-771	F	1900		01	1923	13	1981	108	C2	0.0	Z9C	35	0	549	0
03-774	F	1909		01	1924	3	1977	1	B6	0.0	Z9C	0	0	3	0
03-775	F	1922		01	1942	52	1974	4	B3	0.0	Z9C	1	0	11	0
03-778	F	1904		01	1923	104	1973	54	B1	0.0	Z9C	16	0	252	0
03-779	F	1905	1942	01	1922	+0	1979	1835	A1	0.0	F6	347	0	2651	0
03-782	F	1908		01	1923	5	1981	0	C6	0.0	Z9C	0	0	2	0
03-784	F	1905		01	1923	178	1954	750	C4	0.0	Z9	173	0	2651	0
03-788	F	1905		01	1926	104	1976	1	B6	0.0	Z9C	0	0	4	0
03-795	F	1897	1944	01	1926	78	1944	8	G6	0.0	Z9	1	0	10	0
03-796	F	1907		01	1925	2	1972	0	B6	0.0	Z9C	0	0	1	0
03-798	F	1915		01	1935	280	1978	2	C6	0.0	Z9C	0	0	5	0
03-801	F	1906		01	1924	13	1981	1	C6	0.0	Z9C	0	0	5	0
03-807	F	1923		01	1954	780	1973	0	B6	0.0	Z9C	0	0	0	0
03-810	F	1919		01	1934	312	1972	2	B6	0.0	Z9C	0	0	6	0
03-817	F	1907		01	1926	13	1978	0	C6	0.0	Z9C	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
03-818	F	1902		01	1927	62	1975	4	B3	0.0	Z9C	1	0	18	0
03-825	F	1906		01	1922	4	1981	1	C6	0.0	Z9C	0	0	4	0
03-828	M	1915		17	1950	936	1980	0	C6	0.0	Z9C	0	0	0	0
03-834	F	1907		01	1925	+0	1976	1	B3	0.0	Z9C	0	0	6	0
03-836	F	1908	1980	01	1924	23	1967	0	C6	0.0	Z9	0	0	0	0
03-838	F	1928		01	1947	130	1975	2	B3	0.0	Z9C	1	0	6	0
03-842	F	1910	1983	01	1926	416	1976	3	B2	0.0	Z9C	1	0	13	0
03-845	F	1908		01	1927	104	1979	0	C6	0.0	Z9C	0	0	0	0
03-850	F	1923		01	1942	78	1979	7	C3	0.0	Z9C	2	0	23	0
05-001	F	1900		01	1919	52	1981	57	C2	0.00027	Z7C	19	9	312	139
05-002	F	1903	1973	01	1917	104	1971	2	B6	0.0	Z9B	1	0	9	0
05-003	F	1900	1959	01	1917	8	1958	0	G6	0.0	Z9	0	0	0	0
05-004	F	1904		01	1920	104	1959	12	G6	0.01600	Z7	3	5	50	77
05-005	F	1901	1980	01	1916	13	1960	0	G6	0.0	Z9	0	0	0	0
05-007	F	1896		01	1920	95	1967	23	B2	0.00600	Z7B	7	11	107	164
05-008	M	1894	1964	07	1916	104	1963	4	CL	0.0	Z9C	1	0	11	0
05-010	F	1901	1974	01	1921	34	1961	4	CL	0.01200	Z7C	1	2	15	24
05-011	F	1902	1981	01	1917	52	1959	12	G6	0.0	Z9	3	0	53	0
05-012	F	1901	1959	01	1917	52	1979	16	A1	0.0	Z9A	5	0	55	0
05-014	F	1900		01	1916	208	1981	105	C2	0.00051	B6C	36	39	588	583
05-015	F	1891		01	1916	67	1978	4	C6	0.0	Z9B	1	0	20	0
05-016	M	1891	1965	06	1916	100	1958	15	G4	0.0	Z9	4	0	40	0
05-017	F	1894	1980	01	1919	+0	1968	5	G6	0.00520	Z7	2	3	24	46
05-018	M	1886	1979	06	1918	156	1971	4	B3	0.00180	Z7B	1	1	14	12
05-019	F	1885	1968	01	1921	2	1960	0	G6	0.01400	Z7	0	0	0	0
05-020	F	1898	1980	01	1917	52	1959	3	G6	0.0	Z9	1	0	13	0
05-022	F	1900	1969	07	1916	32	1964	4	CL	0.0	Z9C	1	0	17	0
05-023	F	1899	1960	01	1918	104	1960	38	C2	0.00320	Z7C	10	5	126	73
05-024	M	1890	1965	06	1916	208	1961	4	CL	0.01200	Z7C	1	2	11	27
05-025	F	1893		01	1917	78	1971	86	B1	0.00020	Z7B	27	4	444	53
05-037	F	1898	1977	01	1916	260	1971	2	B6	0.0	Z9B	1	0	10	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
05-038	F	1901		07	1916	156	1972	99	G4	0.0	Z9	32	0	519	0
05-039	F	1899		07	1917	156	1980	18	C2	0.00043	Z7C	6	5	97	68
05-040	F	1899		01	1917	54	1971	10	B2	0.0	Z9B	3	0	52	0
05-042	F	1918		01	1940	130	1972	1	B6	0.0	Z9B	0	0	3	0
05-043	M	1888	1960	06	1919	208	1965	0	F6	0.00430	Z7F	0	0	0	0
05-044	M	1895	1975	06	1915	468	1971	2	B6	0.0	Z9B	1	0	7	0
05-045	F	1899	1960	01	1917	60	1965	5	F4	0.0	Z9F	1	0	17	0
05-049	F	1905		01	1923	13	1965	6	C3	0.0	Z9C	2	0	26	0
05-072	M	1893	1950	07	1919	13	1976	0	A6	0.00100	Z7	0	0	0	0
05-088	F	1886		01	1917	4	1959	4	G6	0.0	Z9	1	0	18	0
05-089	F	1900	1982	01	1916	78	1971	13	B2	0.0	Z9B	4	0	68	0
05-092	F	1901	1982	01	1916	104	1959	6	G6	0.0	Z9	2	0	27	0
05-093	F	1897	1974	71	1915	78	1961	6	C6	0.0	Z9C	2	0	26	0
05-094	F	1927		01	1946	39	1973	6	B3	0.0	Z9B	1	0	15	0
05-096	F	1901	1971	01	1918	26	1962	234	C2	0.00050	Z7C	66	7	949	102
05-097	M	1892	1976	06	1918	26	1961	4	CL	0.00050	Z7C	1	0	12	1
05-100	F	1907		01	1919	156	1968	4	G6	0.00520	Z7	1	2	19	30
05-101	F	1902		01	1924	6	1964	4	CL	0.00850	Z7C	1	1	17	18
05-102	F	1901	1982	01	1915	364	1960	6	C6	0.00350	Z7C	2	1	27	13
05-103	F	1906		01	1923	4	1959	1	G6	0.01600	Z7	0	0	4	5
05-104	F	1900		01	1918	13	1964	4	CL	0.00040	Z7C	1	0	19	2
05-105	M	1903	1959	07	1918	30	1959	0	G6	0.00070	Z7	0	0	0	0
05-111	M	1895	1977	07	1920	312	1970	5	G6	0.00660	Z7	1	3	15	31
05-116	F	1898	1959	01	1917	52	1972	19	A1	0.0	Z9A	5	0	64	0
05-117	M	1887	1968	06	1915	208	1964	4	CL	0.0	Z9C	1	0	12	0
05-118	F	1901		01	1917	65	1977	2	B3	0.0	Z9B	1	0	11	0
05-119	F	1905		01	1924	212	1977	10	B2	0.00175	Z7	3	3	47	46
05-120	F	1890		07	1919	6	1959	5	G6	0.00770	Z7	1	1	22	20
05-121	F	1906		01	1921	26	1980	8	C3	0.00117	Z7C	3	4	41	58
05-122	M	1879	1962	07	1922	208	1979	5	F4	0.00144	Z7F	1	2	11	16
05-123	F	1897	1972	01	1918	1	1960	4	G6	0.00060	Z7	1	0	16	2

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
05-125	F	1902	1976	07	1916	104	1959	26	G4	0.0	Z9	7	0	111	0
05-126	M	1889	1970	01	1921	52	1970	0	B6	0.0	Z9B	0	0	0	0
05-127	M	1893		06	1918	999	1967	20	B2	0.0	Z9B	5	0	56	0
05-129	F	1900	1969	07	1917	104	1960	4	CL	0.0	Z9C	1	0	16	0
05-130	F	1920		01	1940	78	1972	0	B6	0.0	Z9B	0	0	0	0
05-132	F	1898	1982	07	1918	52	1969	0	G6	0.00020	Z7	0	0	0	0
05-133	M	1903	1967	07	1918	13	1959	0	G6	0.00070	Z7	0	0	0	0
05-134	F	1900		01	1917	6	1959	9	G6	0.0	Z9	3	0	41	0
05-135	F	1919		01	1941	106	1976	0	B6	0.0	Z9B	0	0	0	0
05-136	M	1896	1966	06	1917	78	1959	94	G4	0.0	Z9	26	0	249	0
05-138	F	1917		01	1941	104	1968	5	B3	0.0	Z9B	1	0	13	0
05-139	F	1891	1966	01	1919	70	1962	4	CL	0.00540	Z7C	1	1	15	16
05-140	F	1897	1960	01	1917	168	1978	670	F4	0.00082	F2	185	206	2251	3090
05-142	F	1904		01	1919	39	1960	11	G6	0.00680	Z7	3	3	49	43
05-143	F	1899	1962	07	1918	+0	1961	4	CL	0.00050	Z7C	1	0	14	2
05-145	M	1883	1961	07	1916	572	1961	4	CL	0.00150	Z7C	1	0	9	2
05-146	M	1897		06	1920	286	1968	2	G6	0.00490	Z7	1	1	6	7
05-150	F	1899	1969	07	1917	6	1960	45	G6	0.0	Z9	13	0	179	0
05-151	F	1897		01	1924	95	1963	7	C3	0.00960	Z7C	2	2	28	27
05-154	F	1900	1978	01	1916	11	1970	0	G6	0.0	Z9	0	0	0	0
05-155	F	1898	1965	07	1916	28	1963	4	CL	0.0	Z9C	1	0	16	0
05-160	F	1917		01	1942	156	1969	0	G6	0.0	Z9	0	0	0	0
05-161	M	1901	1979	06	1918	9	1971	0	B6	0.00016	Z7B	0	0	0	0
05-162	F	1914		07	1942	+0	1960	29	G6	0.0	Z9	5	0	63	0
05-163	M	1912	1970	07	1941	104	1960	35	G6	0.0	Z9	6	0	42	0
05-165	F	1899	1964	01	1919	13	1972	1	A6	0.0	Z9A	0	0	3	0
05-172	F	1907	1960	01	1934	999	1960	24	G4	0.0	Z9	4	0	26	0
05-174	F	1902		01	1919	130	1977	0	C6	0.00126	Z7	0	0	0	0
05-179	F	1921	1982	01	1940	182	1974	0	B6	0.0	Z9B	0	0	0	0
05-181	F	1901		01	1918	4	1970	0	B6	0.00018	Z7B	0	0	0	0
05-184	M	1901	1974	41	1922	156	1964	5	C6	0.0	Z9C	1	0	14	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
05-185	F	1912		01	1941	208	1972	2	B6	0.0	Z9B	0	0	5	0
05-186	F	1922		01	1941	208	1982	0	B3	0.0	Z9B	0	0	0	0
05-188	M	1889	1964	07	1917	104	1961	4	CL	0.0	Z9C	1	0	10	0
05-189	M	1890	1972	07	1921	104	1964	4	CL	0.00850	Z7C	1	2	11	17
05-194	F	1902	1965	01	1926	5	1975	31	F4	0.0	Z9	8	0	97	0
05-197	M	1898	1981	07	1919	7	1973	0	B6	0.00140	Z7B	0	0	0	0
05-199	F	1901		16	1917	2	1967	0	B6	0.0	Z9B	0	0	0	0
05-201	F	1919	1982	01	1941	221	1976	6	B3	0.0	Z9B	1	0	17	0
05-203	F	1899		01	1919	52	1960	0	G6	0.00680	Z7	0	0	0	0
05-204	M	1880	1961	07	1918	78	1978	0	F6	0.00037	Z7F	0	0	0	0
05-205	F	1907	1981	01	1924	208	1961	4	CL	0.0	Z9C	1	0	15	0
05-206	F	1894	1981	01	1922	52	1971	2	B6	0.00360	Z7B	1	1	9	12
05-207	M	1893	1980	06	1917	+0	1962	6	G6	0.0	Z9	2	0	20	0
05-210	F	1899	1971	01	1916	158	1977	1060	A1	0.0	Z9A	334	0	4814	0
05-212	F	1903		07	1918	8	1965	4	CL	0.00030	Z7C	1	0	19	2
05-215	F	1886	1968	01	1917	208	1969	1410	A1	0.00198	A3	425	363	5776	5462
05-237	M	1896	1969	06	1920	364	1961	4	CL	0.0	Z9C	1	0	10	0
05-246	F	1884	1969	06	1911	728	1962	4	CL	0.0	Z9C	1	0	16	0
05-251	F	1896	1981	01	1917	34	1965	13	G4	0.0	Z9	4	0	62	0
05-252	F	1890	1976	01	1917	52	1964	4	CL	0.0	Z9C	1	0	18	0
05-255	M	1886	1966	07	1920	104	1964	5	C6	0.00850	Z7C	1	2	13	24
05-257	F	1895	1975	01	1932	1248	1972	3	G6	0.0	Z9	1	0	7	0
05-258	F	1901		01	1917	1	1970	0	G6	0.0	Z9	0	0	0	0
05-259	F	1900		07	1917	52	1960	6	G6	0.0	Z9	2	0	28	0
05-260	F	1898	1980	07	1917	32	1960	0	G6	0.0	Z9	0	0	0	0
05-261	F	1892	1977	01	1943	104	1960	4	CL	0.0	Z9C	1	0	7	0
05-262	F	1917		01	1942	260	1982	6	B2	0.0	Z9C	2	0	18	0
05-263	M	1883	1967	07	1919	104	1962	4	CL	0.00800	Z7C	1	1	11	16
05-264	M	1903	1983	07	1917	5	1961	4	CL	0.0	Z9C	1	0	13	0
05-265	M	1884	1963	07	1916	104	1962	4	CL	0.0	Z9C	1	0	11	0
05-266	M	1881	1970	07	1918	130	1964	4	CL	0.00200	Z7C	1	1	11	6

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
05-268	F	1893		01	1918	39	1960	4	CL	0.00060	Z7C	1	0	18	2
05-269	M	1887	1971	07	1918	52	1964	4	CL	0.00040	Z7C	1	0	12	1
05-270	M	1901		07	1916	52	1961	8	C3	0.0	Z9C	2	0	27	0
05-272	M	1895		06	1918	65	1972	0	B6	0.00014	Z7B	0	0	0	0
05-273	F	1889	1968	01	1918	104	1960	4	CL	0.01400	Z7C	1	2	15	34
05-274	F	1903		07	1920	4	1970	0	G6	0.0	Z9	0	0	0	0
05-276	F	1906		01	1921	75	1961	4	CL	0.01200	Z7C	1	2	17	23
05-277	M	1894	1973	06	1918	104	1960	4	CL	0.00320	Z7C	1	1	11	6
05-278	F	1893	1965	01	1917	52	1964	37	C2	0.0	Z9F	11	0	145	0
05-279	F	1896	1979	01	1917	1820	1969	0	G6	0.0	Z9	0	0	0	0
05-281	F	1898	1964	01	1916	148	1963	660	B2	0.00216	F1	191	105	2519	1580
05-282	F	1898		01	1917	34	1964	8	C6	0.0	Z9C	2	0	39	0
05-284	F	1899	1973	01	1919	156	1969	218	B1	0.00080	Z7B	65	19	930	284
05-286	M	1901	1963	06	1916	104	1965	1	F4	0.0	Z9F	0	0	1	0
05-287	M	1889	1970	07	1917	390	1965	4	CL	0.00420	Z7C	1	1	11	11
05-288	F	1897		01	1918	10	1960	4	CL	0.00060	Z7C	1	0	18	2
05-290	F	1898	1967	01	1918	52	1960	8	C3	0.00060	Z7C	2	0	30	3
05-291	F	1902	1974	01	1920	8	1968	4	G6	0.00540	Z7	1	2	17	33
05-292	M	1904	1974	07	1918	+0	1965	4	CL	0.00033	Z7C	1	0	13	1
05-304	F	1897		01	1921	26	1962	4	CL	0.01100	Z7C	1	2	17	26
05-306	F	1903	1983	01	1921	156	1981	4	C3	0.00107	Z7C	1	2	21	26
05-307	F	1920		01	1944	73	1982	0	B6	0.0	Z9C	0	0	1	0
05-308	M	1893	1964	07	1916	208	1962	4	CL	0.00130	Z7C	1	0	11	3
05-310	F	1894	1965	01	1916	78	1964	5	C6	0.0	Z9C	1	0	20	0
05-311	M	1887	1961	06	1920	156	1960	4	CL	0.01400	Z7C	1	2	9	17
05-312	M	1886	1961	01	1919	34	1961	2	F6	0.00610	Z7F	1	1	5	6
05-318	M	1901	1961	07	1918	+0	1965	4	F4	0.00030	Z7F	1	0	10	1
05-321	F	1899		01	1916	208	1966	16	G6	0.00330	Z7	5	5	78	80
05-322	M	1900	1975	07	1917	312	1973	4	B3	0.0	Z7B	1	0	13	0
05-323	F	1899	1961	01	1915	26	1961	2	A5	0.0	Z9	1	0	7	0
05-349	F	1884	1956	01	1919	+0	1979	7	A2	0.00075	Z7	2	2	22	31

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
05-351	F	1891		01	1917	30	1968	23	G6	0.0	Z9	7	0	116	0
05-352	M	1900	1963	07	1917	40	1964	1	F6	0.0	Z9F	0	0	3	0
05-353	M	1900		07	1915	13	1978	0	C6	0.0	Z9B	0	0	0	0
05-357	F	1890	1978	07	1917	104	1972	3	G6	0.0	Z9	1	0	15	0
05-360	M	1892	1968	01	1914	+0	1963	4	CL	0.0	Z9C	1	0	12	0
05-363	F	1899	1980	07	1917	9	1964	4	CL	0.0	Z9C	1	0	19	0
05-368	F	1901		07	1917	104	1977	0	B6	0.0	Z9C	0	0	0	0
05-369	F	1901		07	1919	26	1978	1	B6	0.00077	Z7B	0	0	5	5
05-370	F	1895		01	1920	26	1965	4	CL	0.00760	Z7C	1	2	18	30
05-372	F	1888	1970	01	1916	104	1968	14	G4	0.0	Z9	4	0	62	0
05-374	F	1905		01	1923	8	1980	0	C6	0.00124	Z7C	0	0	0	0
05-377	F	1895	1974	01	1916	15	1969	0	G6	0.0	Z9	0	0	0	0
05-380	F	1904	1970	07	1925	104	1962	4	CL	0.01100	Z7C	1	1	13	13
05-383	F	1901	1982	06	1917	165	1973	73	B1	0.00060	Z7B	23	10	374	156
05-387	M	1902		06	1918	9	1975	0	B6	0.00010	Z7B	0	0	0	0
05-395	F	1911		01	1928	728	1977	0	C6	0.0	Z9	0	0	0	0
05-397	F	1900	1976	07	1918	13	1962	4	CL	0.0	Z9C	1	0	17	0
05-399	M	1892	1982	07	1916	104	1961	4	CL	0.0	Z9C	1	0	13	0
05-401	M	1898		76	1917	169	1971	5	B3	0.00170	Z7B	2	2	18	16
05-407	F	1898		01	1916	9	1978	0	B6	0.0	Z9B	0	0	0	0
05-409	F	1900	1983	07	1918	61	1974	0	B6	0.00011	Z7B	0	0	0	0
05-410	F	1899		01	1916	26	1980	2	C6	0.0	Z9C	1	0	10	0
05-413	F	1900	1971	01	1916	39	1969	18	B2	0.0	Z9B	6	0	82	0
05-420	F	1889	1935	01	1917	104	1970	50	A1	0.0	Z9A	9	0	60	0
05-437	F	1888		07	1923	26	1971	3	B3	0.00350	Z7B	1	1	14	16
05-438	F	1907		01	1926	13	1961	4	CL	0.0	Z9C	1	0	15	0
05-439	F	1898	1970	01	1916	104	1967	200	G6	0.0	Z9	61	0	872	0
05-440	F	1896	1975	01	1922	1	1971	0	B6	0.00360	Z7B	0	0	0	0
05-442	F	1888		07	1917	6	1962	8	G6	0.0	Z9	2	0	38	0
05-443	F	1922		07	1941	52	1972	3	B6	0.0	Z9B	1	0	9	0
05-444	M	1899	1963	06	1917	43	1961	4	CL	0.0	Z9C	1	0	11	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
05-446	M	1888	1971	45	1925	+0	1964	4	CL	0.0	Z9C	1	0	10	0
05-447	F	1902		01	1916	9	1970	2	B6	0.0	Z9B	1	0	11	0
05-448	F	1903		01	1916	1	1961	4	CL	0.0	Z9C	1	0	19	0
05-449	F	1892	1961	01	1919	52	1961	4	CL	0.00610	Z7C	1	1	13	16
05-450	F	1903		07	1918	117	1971	1	B6	0.00090	Z7B	0	0	5	2
05-459	F	1917		01	1933	208	1961	8	C6	0.0	Z9C	2	0	23	0
05-460	F	1898	1979	07	1916	182	1961	4	CL	0.0	Z9C	1	0	18	0
05-464	F	1895	1969	01	1917	+0	1968	5	G6	0.0	Z9	2	0	22	0
05-473	M	1899	1970	06	1921	26	1962	4	CL	0.01100	Z7C	1	2	11	18
05-528	F	1892	1981	01	1917	52	1967	0	G6	0.0	Z9	0	0	0	0
05-541	F	1913		01	1937	884	1972	0	B6	0.0	Z9B	0	0	0	0
05-546	F	1902		07	1918	52	1973	1	B6	0.00012	Z7B	0	0	5	0
05-551	F	1895	1981	01	1918	9	1970	15	G6	0.00018	Z7	5	0	75	7
05-555	F	1898	1965	07	1917	27	1975	1	A6	0.0	Z9	0	0	4	0
05-560	M	1894	1965	07	1921	260	1962	4	CL	0.01100	Z7C	1	1	9	13
05-574	F	1903		01	1918	1	1977	0	C6	0.00008	Z7	0	0	0	0
05-580	M	1904	1975	07	1919	6	1968	4	G6	0.00260	Z7	1	1	13	13
05-602	M	1899		06	1925	1300	1975	0	B6	0.0	Z9B	0	0	0	0
05-611	F	1900	1938	01	1914	156	1974	0	A6	0.0	Z9A	0	0	0	0
05-631	F	1897	1976	01	1917	17	1970	0	G6	0.0	Z9	0	0	0	0
05-639	M	1906	1962	06	1922	39	1964	1	F6	0.00850	Z7F	0	0	2	4
05-674	M	1922		06	1946	156	1965	4	CL	0.0	Z9C	1	0	6	0
05-688	F	1921	1976	01	1939	130	1965	5	C6	0.0	Z9C	1	0	12	0
05-736	F	1898	1954	06	1918	156	1972	150	F4	0.00410	F1	38	91	407	1359
05-737	M	1895	1957	06	1918	156	1971	10	F4	0.00462	Z4F	3	6	21	68
05-742	F	1898	1975	01	1916	30	1969	0	G6	0.0	Z9	0	0	0	0
05-751	F	1901	1933	01	1920	+0	1969	0	A6	0.00500	Z7A	0	0	0	0
05-765	F	1900		07	1916	117	1964	4	CL	0.0	Z9C	1	0	19	0
05-802	F	1893	1980	01	1918	+0	1972	1	B6	0.00014	Z7B	0	0	3	0
05-818	F	1901	1969	01	1918	52	1967	25	B2	0.00026	Z7B	7	1	104	11
05-873	F	1894		07	1917	286	1962	39	C2	0.00350	Z7C	11	6	175	95

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
05-880	F	1921		01	1939	520	1974	2	B6	0.0	Z9B	0	0	5	0
05-882	F	1917	1965	01	1935	468	1964	13	G6	0.0	Z9	3	0	24	0
05-885	F	1917		01	1939	572	1969	0	G6	0.0	Z9	0	0	0	0
05-892	F	1904	1982	01	1917	4	1969	160	G4	0.0	Z9	50	0	814	0
05-897	F	1699	1968	01	1917	69	1968	1310	G4	0.0	Z9	400	0	5541	0
05-898	F	1919		01	1936	468	1972	0	B6	0.0	Z9B	0	0	0	0
05-900	F	1919	1973	01	1936	312	1972	3	B3	0.0	Z9C	1	0	8	0
05-901	F	1918		01	1934	468	1972	2	B6	0.0	Z9B	0	0	6	0
05-902	F	1919		01	1936	988	1962	6	C6	0.0	Z9C	1	0	11	0
05-905	F	1916		76	1937	156	1972	0	B6	0.0	Z9B	0	0	0	0
05-906	F	1913		01	1935	624	1972	2	B6	0.0	Z9B	0	0	6	0
05-907	F	1915		01	1935	260	1972	3	B6	0.0	Z9C	1	0	10	0
05-911	M	1886	1982	07	1923	6	1972	0	G6	0.00310	Z7	0	0	0	0
05-912	M	1877	1951	07	1918	26	1969	0	A6	0.00020	Z7A	0	0	0	0
05-917	F	1902	1983	01	1918	39	1982	76	C2	0.00004	Z9	26	3	426	39
05-920	M	1895	1963	06	1917	43	1962	4	CL	0.0	Z9C	1	0	11	0
05-921	F	1896		01	1916	30	1969	67	G4	0.0	Z9	21	0	349	0
05-942	M	1901		06	1918	9	1975	0	B6	0.00010	Z7B	0	0	0	0
05-949	M	1899	1974	06	1921	422	1968	0	G6	0.0	Z9	0	0	0	0
05-953	F	1902	1978	01	1918	65	1977	1200	F4	0.00008	Z7F	396	36	6110	547
05-962	F	1894	1977	01	1918	84	1964	47	C2	0.00200	Z7C	14	7	207	99
05-974	F	1900		07	1918	104	1970	0	G6	0.00100	Z7	0	0	0	0
05-979	F	1897		01	1917	4	1982	124	C3	0.0	Z9	43	0	715	0
05-993	M	1902	1972	07	1917	6	1971	0	B6	0.0	Z9B	0	0	0	0
05-994	F	1886		01	1922	26	1967	9	G4	0.00570	Z7	3	3	41	51
05-998	F	1902		01	1918	3	1980	0	C6	0.00005	Z7C	0	0	0	0
09-001	F	1901		01	1917	39	1971	4	B3	0.0	Z9B	1	0	21	0
09-002	F	1902	1970	01	1917	17	1959	10	B3	0.0	Z9B	3	0	40	0
09-003	M	1892	1963	06	1914	572	1959	410	B1	0.0	Z9B	110	0	989	0
09-004	F	1890	1961	01	1912	416	1960	550	C2	0.0	Z9C	156	0	2013	0
09-006	F	1898	1971	61	1917	65	1963	1	B6	0.0	Z9B	0	0	4	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
09-007	F	1901	1965	01	1917	104	1960	33	C2	0.0	Z9C	9	0	121	0
09-008	F	1898		01	1917	8	1960	20	C6	0.0	Z9C	6	0	93	0
09-009	F	1893	1969	01	1915	78	1960	2	B6	0.0	Z9B	1	0	8	0
09-010	F	1897	1964	01	1914	+0	1960	10	C6	0.0	Z9C	3	0	40	0
09-013	F	1900	1976	01	1917	13	1971	4	B3	0.0	Z9B	1	0	19	0
09-015	M	1890	1972	04	1914	52	1960	0	G6	0.0	Z9	0	0	0	0
09-019	F	1903	1981	01	1917	18	1975	0	B6	0.0	Z9B	0	0	0	0
09-020	F	1897	1968	01	1917	156	1963	1	B6	0.0	Z9B	0	0	4	0
09-024	M	1873	1960	06	1915	+0	1960	0	F6	0.0	Z9	0	0	0	0
09-026	F	1902		01	1917	48	1978	16	B1	0.0	Z9B	5	0	89	0
09-028	F	1897	1976	01	1916	78	1975	60	B2	0.0	Z9B	20	0	305	0
09-029	F	1901	1962	01	1917	13	1960	16	C2	0.0	Z9C	5	0	58	0
09-031	F	1897		07	1913	364	1960	286	C2	0.0	Z9	81	0	1345	0
09-032	F	1902	1969	01	1917	52	1969	97	B1	0.0	Z9B	30	0	421	0
09-038	F	1903		01	1919	1	1960	0	B6	0.0	Z9B	0	0	0	0
09-041	M	1889	1952	06	1914	260	1965	114	A1	0.0	Z9A	29	0	229	0
09-043	F	1898	1976	01	1917	26	1971	3	B6	0.0	Z9B	1	0	15	0
09-044	F	1900	1955	01	1917	13	1975	17	A2	0.0	Z9	4	0	52	0
09-046	F	1902	1965	01	1917	104	1960	10	C3	0.0	Z9C	3	0	37	0
09-049	F	1902	1983	01	1915	+0	1969	14	G6	0.0	Z9	4	0	75	0
09-051	F	1900	1971	01	1917	104	1960	50	C6	0.0	Z9C	14	0	199	0
09-052	F	1900	1971	01	1916	52	1960	20	C6	0.0	Z9C	6	0	83	0
09-053	M	1874	1966	04	1919	+0	1960	81	B1	0.0	Z9B	22	0	210	0
09-057	F	1890	1973	01	1917	52	1960	0	B6	0.0	Z9B	0	0	0	0
09-058	F	1899		01	1917	39	1960	4	B6	0.0	Z9B	1	0	18	0
09-059	F	1903	1972	01	1917	1	1971	2	B6	0.0	Z9B	1	0	9	0
09-060	F	1899	1975	01	1917	65	1969	43	B2	0.0	Z9B	13	0	200	0
09-061	F	1892		01	1914	208	1970	0	G6	0.0	Z9	0	0	0	0
09-062	F	1901		01	1918	52	1972	4	B3	0.0	Z9B	1	0	21	0
09-064	F	1891		01	1916	9	1973	1	B6	0.0	Z9B	0	0	5	0
09-065	F	1887	1975	07	1914	78	1960	1	B6	0.0	Z9B	0	0	5	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
09-066	F	1899	1983	01	1917	8	1972	2	B6	0.0	Z9B	1	0	11	0
09-070	M	1875	1967	06	1913	208	1960	3	B6	0.0	Z9B	1	0	9	0
09-071	F	1897	1977	01	1917	104	1975	2	B6	0.0	Z9B	1	0	10	0
09-072	F	1893	1974	01	1917	39	1972	2	B6	0.0	Z9C	1	0	10	0
09-073	M	1886	1963	06	1916	468	1962	0	B6	0.0	Z9B	0	0	0	0
09-074	F	1892	1976	01	1920	104	1962	13	G6	0.0	Z9	4	0	52	0
09-075	M	1893	1967	06	1913	884	1963	1	B6	0.0	Z9B	0	0	3	0
09-076	M	1882	1966	06	1913	1872	1964	14	D3	0.0	Z9D	3	0	25	0
09-077	M	1894		06	1914	520	1972	2	B6	0.0	Z9B	1	0	7	0
09-078	M	1883	1966	06	1911	832	1963	3	B6	0.0	Z9B	1	0	8	0
09-079	M	1891	1981	06	1916	570	1962	0	G6	0.0	Z9	0	0	0	0
09-080	M	1886	1982	06	1919	312	1962	5	G6	0.0	Z9	1	0	15	0
09-082	M	1892	1981	06	1916	312	1979	6	B3	0.0	Z9B	2	0	23	0
09-083	M	1889	1964	06	1915	17	1962	5	G6	0.0	Z9	1	0	14	0
09-084	M	1888	1927	06	1912	676	1965	382	A1	0.0	Z9A	42	0	131	0
09-086	M	1895	1979	06	1921	78	1974	1	B6	0.0	Z9B	0	0	3	0
09-088	M	1900		06	1922	338	1971	18	B2	0.0	Z9B	5	0	57	0
09-089	M	1890	1973	06	1915	78	1959	64	C2	0.0	Z9C	18	0	194	0
09-090	M	1888	1971	06	1913	78	1963	0	G6	0.0	Z9	0	0	0	0
09-095	M	1894	1975	06	1918	416	1975	0	B6	0.0	Z9B	0	0	0	0
09-096	M	1892	1978	06	1919	17	1963	9	G6	0.0	Z9	3	0	28	0
09-097	M	1896		07	1916	988	1974	1	B6	0.0	Z9B	0	0	3	0
09-098	M	1902	1971	06	1921	104	1963	14	G6	0.0	Z9	4	0	37	0
09-099	M	1898	1971	06	1913	208	1963	1	G6	0.0	Z9	0	0	3	0
09-100	M	1888	1980	06	1918	364	1963	9	G6	0.0	Z9	2	0	27	0
09-101	M	1884	1964	06	1920	39	1963	6	G6	0.0	Z9	2	0	15	0
09-102	M	1882	1951	46	1915	1	1964	150	A1	0.0	Z9A	38	0	306	0
09-103	M	1895	1971	06	1918	416	1965	1	G6	0.0	Z9	0	0	3	0
09-104	M	1880	1967	06	1906	364	1965	42	B2	0.0	Z9B	13	0	146	0
09-105	M	1886	1928	06	1912	832	1966	1390	A1	0.00093	A6	112	17	333	114
09-106	M	1901		06	1919	156	1979	0	B6	0.0	Z9B	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
09-107	M	1897	1974	06	1913	104	1965	1	G6	0.0	Z9	0	0	3	0
09-108	M	1891	1981	06	1915	104	1965	4	G6	0.0	Z9	1	0	14	0
09-109	M	1895	1982	06	1914	104	1965	4	G6	0.0	Z9	1	0	15	0
09-110	M	1900		06	1914	52	1965	7	G6	0.0	Z9	2	0	26	0
09-111	M	1874	1944	06	1913	520	1967	0	A6	0.0	Z9A	0	0	0	0
09-112	M	1898	1979	06	1940	416	1966	84	G4	0.0	Z9	17	0	130	0
09-115	M	1893		06	1920	52	1969	3	G6	0.0	Z9	1	0	10	0
09-117	F	1899		01	1917	24	1971	4	B3	0.0	Z9B	1	0	21	0
09-118	F	1901		07	1921	+0	1970	50	G4	0.0	Z9	15	0	239	0
09-120	M	1889	1945	06	1918	104	1974	1	A6	0.0	Z9	0	0	2	0
09-123	M	1890		06	1917	156	1979	0	B6	0.0	Z9B	0	0	0	0
10-007	F	1916		01	1934	1144	1981	6	C3	0.0	Z9C	1	0	17	0
10-008	F	1904		01	1918	13	1981	1	C6	0.00005	Z7C	0	0	6	1
10-010	F	1895	1975	05	1930	+0	1971	8600	B1	0.0	Z9C	2361	0	30382	0
10-012	M	1886	1941	05	1925	+0	1972	0	A6	0.0	Z9	0	0	0	0
10-018	F	1920		01	1952	416	1975	1	B6	0.0	Z9B	0	0	2	0
10-024	M	1914		06	1936	1612	1971	50	G4	0.0	Z9	8	0	60	0
10-025	M	1937		07	1963	416	1971	7	B3	0.0	Z9C	0	0	2	0
10-026	M	1948		07	1968	200	1971	2	B6	0.0	Z9C	0	0	0	0
10-027	F	1928		01	1946	156	1972	0	B6	0.0	Z9C	0	0	0	0
10-028	M	1886	1976	06	1918	156	1976	0	B6	0.0	Z9B	0	0	0	0
10-031	F	1928		01	1946	52	1979	3	C6	0.0	Z9C	1	0	8	0
10-032	M	1937		07	1961	156	1972	0	B6	0.0	Z9C	0	0	0	0
10-033	F	1927		01	1946	264	1974	3	B3	0.0	Z9C	1	0	8	0
10-034	F	1919		01	1943	202	1973	9	B2	0.0	Z9C	2	0	23	0
10-035	F	1922		16	1942	674	1982	7	B1	0.0	Z9C	2	0	18	0
10-036	F	1920		76	1945	208	1972	0	B6	0.0	Z9C	0	0	0	0
10-037	F	1927		01	1951	52	1976	3	B6	0.0	Z9C	1	0	7	0
10-038	F	1929		01	1947	78	1974	1	B6	0.0	Z9C	0	0	1	0
10-039	F	1922		07	1942	260	1972	4	B3	0.0	Z9C	1	0	10	0
10-040	F	1917		01	1946	+0	1972	0	B6	0.0	Z9C	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
10-041	F	1924		01	1943	13	1972	1	B6	0.0	Z9C	0	0	2	0
10-042	F	1927		01	1947	125	1982	0	B6	0.0	Z9C	0	0	0	0
10-043	F	1919		05	1941	8	1975	0	B6	0.0	Z9B	0	0	0	0
10-044	F	1925		71	1943	273	1982	7	B3	0.0	Z9C	2	0	21	0
10-045	F	1923		01	1946	13	1982	1	B6	0.0	Z9C	0	0	3	0
10-046	F	1927		17	1947	208	1975	0	B6	0.0	Z9C	0	0	0	0
10-047	F	1924		01	1942	52	1974	10	B2	0.0	Z9C	2	0	28	0
10-048	F	1894		06	1917	156	1977	0	B6	0.0	Z9B	0	0	0	0
10-049	F	1926		01	1946	104	1972	0	B6	0.0	Z9C	0	0	0	0
10-050	F	1920		01	1943	114	1982	6	B2	0.0	Z9C	2	0	20	0
10-051	M	1914		06	1931	468	1979	1	C6	0.0	Z9C	0	0	3	0
10-053	F	1926		17	1946	267	1982	1	B6	0.0	Z9C	0	0	1	0
10-054	F	1926		71	1946	304	1972	1	B6	0.0	Z9C	0	0	3	0
10-055	M	1922		08	1922	39	1972	0	B6	0.00040	Z7B	0	0	0	0
10-056	M	1924		08	1924	39	1972	2	B6	0.00040	Z7B	1	0	6	1
10-057	F	1929		01	1946	52	1972	1	B6	0.0	Z9C	0	0	3	0
10-058	F	1923		01	1941	208	1982	5	B2	0.0	Z9B	1	0	16	0
10-059	F	1917		01	1954	143	1980	1	C6	0.0	Z9C	0	0	2	0
10-060	F	1919		01	1943	104	1972	0	B6	0.0	Z9C	0	0	0	0
10-061	F	1923		07	1942	164	1972	6	B3	0.0	Z9C	1	0	16	0
10-062	F	1920		01	1939	182	1972	1	B6	0.0	Z9C	0	0	4	0
10-063	F	1911		01	1928	624	1981	1	C6	0.0	Z9C	0	0	3	0
10-064	F	1921	1983	07	1943	156	1972	0	B6	0.0	Z9C	0	0	0	0
10-065	F	1920		01	1941	260	1972	0	B6	0.0	Z9C	0	0	1	0
10-066	F	1924	1978	01	1942	104	1972	12	B2	0.0	Z9C	3	0	29	0
10-067	F	1923		01	1942	468	1972	8	B2	0.0	Z9C	2	0	19	0
10-068	F	1918		71	1942	78	1972	0	B6	0.0	Z9C	0	0	0	0
10-069	F	1923		01	1947	1300	1972	12	C3	0.0	Z9C	1	0	10	0
10-070	F	1921		01	1945	1352	1982	6	C6	0.0	Z9C	1	0	10	0
10-071	F	1924		01	1943	1716	1983	5	B2	0.0	Z9C	1	0	8	0
10-072	F	192[illegible]		01	1947	1560	1983	5	B2	0.0	Z9C	1	0	6	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
10-075	F	1929		01	1949	277	1982	4	B2	0.0	Z6C	1	0	9	0
10-076	F	1923		01	1951	52	1972	0	B6	0.0	Z9C	0	0	0	0
10-077	F	1920		01	1951	17	1972	1	B6	0.0	Z9C	0	0	1	0
10-078	F	1923		01	1941	715	1980	10	C3	0.0	Z9C	2	0	27	0
10-079	F	1920		01	1940	624	1978	8	C3	0.0	Z9C	2	0	21	0
10-080	F	1913	1983	76	1943	1508	1972	5	B3	0.0	Z9C	1	0	5	0
10-081	F	1916		01	1946	104	1980	3	C3	0.0	Z9C	1	0	9	0
10-082	F	1915		01	1951	758	1972	5	B3	0.0	Z9C	1	0	6	0
10-083	F	1924		01	1943	104	1972	5	B3	0.0	Z9C	1	0	13	0
10-084	F	1928		71	1946	82	1972	0	B6	0.0	Z9C	0	0	0	0
10-085	M	1946		71	1964	17	1972	0	B6	0.0	Z9C	0	0	0	0
10-086	F	1915		01	1943	156	1979	3	C6	0.0	Z9C	1	0	8	0
10-087	F	1920	1978	01	1942	1560	1972	19	B2	0.0	Z9C	2	0	17	0
10-088	F	1923		17	1946	282	1982	1	C6	0.0	Z9C	0	0	1	0
10-089	F	1921		01	1942	13	1972	0	B6	0.0	Z9C	0	0	1	0
10-090	F	1922		01	1941	78	1972	1	B6	0.0	Z9C	0	0	4	0
10-091	M	1883	1952	05	1930	+0	1974	423	A1	0.0	Z9A	84	0	487	0
10-094	M	1905	1974	07	1919	104	1972	0	B6	0.00240	Z7C	0	0	0	0
10-095	F	1927		01	1946	260	1972	5	B3	0.0	Z9C	1	0	12	0
10-096	F	1930		01	1951	832	1982	1	B3	0.0	Z9C	0	0	2	0
10-097	F	1919		01	1943	364	1972	4	B3	0.0	Z9C	1	0	9	0
10-098	F	1917		01	1935	208	1972	4	B3	0.0	Z9C	1	0	13	0
10-099	F	1924		01	1942	104	1980	12	C3	0.0	Z9C	3	0	37	0
10-100	[illegible]	1924		76	1942	78	1972	7	B3	0.0	Z9C	2	0	20	0
10-101	F	1925		01	1943	208	1982	2	C6	0.0	Z9C	1	0	6	0
10-102	F	1926		01	1944	60	1972	1	B6	0.0	Z9C	0	0	2	0
10-103	F	1912		01	1946	104	1978	0	C6	0.0	Z9C	0	0	0	0
10-104	F	1929		01	1948	258	1982	4	B2	0.0	Z9C	1	0	10	0
10-105	F	1927		01	1946	417	1982	0	C6	0.0	Z9C	0	0	0	0
10-106	F	1926		01	1946	104	1982	3	B3	0.0	Z9C	1	0	8	0
10-107	F	1909		01	1926	9	1972	0	B6	0.0	Z9C	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
10-108	F	1916		04	1950	+0	1972	3	B6	0.0	Z9C	1	0	6	0
10-109	F	1951		07	1969	78	1972	0	B6	0.0	Z9C	0	0	0	0
10-110	F	1917		01	1946	520	1972	0	B6	0.0	Z9C	0	0	0	0
10-111	F	1906		01	1923	2	1981	5	C3	0.0	Z9C	2	0	24	0
10-112	M	1902	1980	01	1923	+0	1976	3	B3	0.0	Z9C	1	0	10	0
10-113	F	1924		01	1942	75	1982	0	B6	0.0	Z9C	0	0	1	0
10-114	F	1937		01	1970	390	1982	0	B6	0.0	Z9B	0	0	0	0
10-115	F	1921		07	1970	130	1972	1	B6	0.0	Z9C	0	0	0	0
10-116	F	1924		01	1969	312	1976	5	B2	0.0	Z9C	0	0	2	0
10-117	F	1924		01	1967	208	1972	2	B6	0.0	Z9C	0	0	1	0
10-118	F	1924		01	1945	1820	1982	8	B2	0.0	Z9C	1	0	10	0
10-119	F	1952		71	1971	82	1972	2	B6	0.0	Z9C	0	0	0	0
10-120	F	1950		01	1971	98	1974	4	C3	0.0	Z9C	0	0	1	0
10-121	F	1926	1982	01	1946	7	1972	1	B6	0.0	Z9C	0	0	1	0
10-122	F	1921		07	1921	+0	1972	0	B6	0.0	Z9C	0	0	0	0
10-125	F	1903	1981	01	1917	8	1975	1	B6	0.0	Z9B	0	0	5	0
10-126	F	1927		01	1946	13	1982	1	B6	0.0	Z9C	0	0	2	0
10-128	F	1923		01	1942	364	1972	6	B3	0.0	Z9C	1	0	16	0
10-129	F	1923		01	1942	269	1975	9	B2	0.0	Z9C	2	0	24	0
10-130	F	1922		01	1942	147	1981	14	C3	0.0	Z9C	4	0	42	0
10-131	F	1917		07	1941	260	1972	1	B6	0.0	Z9C	0	0	3	0
10-132	F	1929		07	1970	126	1982	0	B6	0.0	Z9C	0	0	0	0
10-133	F	1910		01	1941	1248	1981	2	C6	0.0	Z9C	0	0	4	0
10-134	F	1913		01	1932	1768	1978	1	C6	0.0	Z9C	0	0	2	0
10-135	F	1922		01	1939	130	1972	6	B3	0.0	Z9C	1	0	18	0
10-136	F	1920		01	1941	26	1972	0	B6	0.0	Z9C	0	0	0	0
10-137	F	1918		01	1935	117	1972	1	B6	0.0	Z9C	0	0	2	0
10-139	F	1922		01	1942	130	1972	3	B6	0.0	Z9C	1	0	8	0
10-140	F	1935		07	1956	17	1972	2	B6	0.0	Z9C	0	0	3	0
10-141	F	1918		01	1945	104	1972	0	B6	0.0	Z9C	0	0	0	0
10-142	F	1922		01	1942	156	1972	2	B6	0.0	Z9C	1	0	6	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
10-144	F	1926		01	1945	156	1972	0	B6	0.0	Z9C	0	0	0	0
10-145	F	1928		07	1946	130	1976	6	C3	0.0	Z9C	1	0	14	0
10-146	F	1921		01	1940	364	1972	4	B3	0.0	Z9C	1	0	10	0
10-147	F	1927		01	1946	156	1972	2	B6	0.0	Z9C	0	0	5	0
10-148	F	1913		01	1935	13	1978	2	C6	0.0	Z9C	1	0	8	0
10-149	F	1924		01	1943	114	1972	4	B3	0.0	Z9C	1	0	12	0
10-150	F	1889	1976	01	1919	13	1972	0	G6	0.0	Z9	0	0	0	0
10-151	M	1887	1979	06	1915	520	1974	0	G8	0.0	Z9	0	0	0	0
10-152	F	1923		01	1941	52	1972	2	B6	0.0	Z9B	0	0	6	0
10-153	F	1921		01	1941	234	1972	1	B6	0.0	Z9B	0	0	3	0
10-160	F	1921		01	1941	208	1976	20	B1	0.0	Z9C	5	0	59	0
10-162	F	1931		01	1951	13	1974	3	B2	0.0	Z9C	1	0	6	0
10-164	F	1915		01	1937	156	1974	0	B6	0.0	Z9C	0	0	0	0
10-165	F	1919		01	1942	416	1972	2	B6	0.0	Z9C	0	0	5	0
10-170	F	1923		01	1941	290	1980	20	B2	0.0	Z9C	5	0	59	0
10-171	F	1924		01	1942	156	1974	3	B3	0.0	Z9C	1	0	8	0
10-172	F	1930	1977	07	1948	60	1974	3	B3	0.0	Z9C	1	0	7	0
10-173	F	1915	1977	01	1948	123	1973	0	B6	0.0	Z9C	0	0	0	0
10-180	F	1919		01	1941	728	1974	9	B2	0.0	Z9C	2	0	20	0
10-181	F	1912		01	1931	287	1978	2	C6	0.0	Z9C	0	0	6	0
10-190	F	1921		01	1951	106	1982	0	B6	0.0	Z9C	0	0	0	0
10-191	F	1940		71	1971	17	1972	2	B6	0.0	Z9C	0	0	0	0
10-192	F	1924		01	1942	78	1974	3	B3	0.0	Z9C	1	0	8	0
10-193	F	1921		01	1941	104	1972	3	B6	0.0	Z9C	1	0	8	0
10-195	F	1920		17	1937	1560	1982	9	C3	0.0	Z9C	2	0	20	0
10-198	F	1920		01	1946	378	1977	8	B3	0.0	Z9C	2	0	20	0
10-201	F	1918		71	1946	1352	1972	9	B2	0.0	Z9C	1	0	8	0
10-202	F	1925		01	1942	53	1974	2	B6	0.0	Z9C	0	0	5	0
10-203	F	1926		01	1946	0	1974	2	B6	0.0	Z9C	0	0	4	0
10-204	F	1950		07	1971	43	1972	6	B3	0.0	Z9C	0	0	1	0
10-205	F	1923		01	1942	39	1972	1	B6	0.0	Z9C	0	0	3	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
10-206	F	1924		01	1943	230	1972	6	B3	0.0	Z9C	1	0	16	0
10-207	F	1923		61	1942	197	1982	5	B2	0.0	Z9C	1	0	17	0
10-208	F	1922		01	1942	7	1972	1	B6	0.0	Z9C	0	0	2	0
10-209	F	1920		01	1942	71	1982	7	B3	0.0	Z9C	2	0	22	0
10-210	F	1909		01	1926	1040	1972	17	B2	0.0	Z9C	4	0	56	0
10-212	M	1950		07	1971	55	1973	1	B6	0.0	Z9C	0	0	0	0
10-213	M	1951		07	1971	45	1973	1	B6	0.0	Z9C	0	0	0	0
10-214	F	1942		07	1972	30	1974	0	B6	0.0	Z9C	0	0	0	0
10-215	F	1921		01	1943	208	1972	1	B6	0.0	Z9C	0	0	2	0
10-216	F	1916		01	1946	1456	1973	2	B6	0.0	Z9C	0	0	2	0
10-218	F	1915		01	1934	492	1973	0	B6	0.0	Z9C	0	0	0	0
10-219	F	1916		16	1937	364	1979	10	C3	0.0	Z9B	3	0	33	0
10-221	F	1917		01	1941	676	1981	0	C6	0.0	Z9C	0	0	0	0
10-222	F	1919		01	1941	234	1972	0	G6	0.0	Z9	0	0	0	0
10-225	F	1911		01	1933	1872	1981	4	C6	0.0	Z9C	1	0	9	0
10-226	F	1923		01	1941	1612	1972	3	B6	0.0	Z9C	0	0	3	0
10-227	M	1912		71	1928	2548	1977	6	B2	0.0	Z9C	1	0	6	0
10-228	F	1912	1981	01	1940	1508	1980	0	C6	0.0	Z9C	0	0	0	0
10-229	F	1920		01	1941	260	1972	1	B6	0.0	Z9C	0	0	3	0
10-230	F	1929		01	1948	13	1973	0	C6	0.0	Z9C	0	0	0	0
10-231	M	1968		08	1968	39	1972	1	C6	0.0	Z9C	0	0	0	0
10-232	M	1969		08	1969	39	1972	0	C6	0.0	Z9C	0	0	0	0
10-233	F	1919		01	1942	92	1976	2	B3	0.0	Z9C	0	0	6	0
10-234	F	1928	1972	07	1959	676	1972	0	B6	0.0	Z9C	0	0	0	0
10-236	F	1919		01	1949	156	1974	0	B6	0.0	Z9C	0	0	0	0
10-237	F	1910		01	1940	156	1977	2	C6	0.0	Z9C	1	0	7	0
10-239	M	1908	1979	06	1934	1300	1976	0	B6	0.0	Z9B	0	0	0	0
10-240	M	1906		06	1931	884	1981	0	C6	0.0	Z9C	0	0	0	0
10-241	F	1904	1978	01	1922	17	1972	0	C6	0.0	Z9C	0	0	0	0
10-242	F	1947		07	1966	156	1974	1	B6	0.0	Z9C	0	0	0	0
10-244	F	1916		01	1943	1	1981	3	C3	0.0	Z9C	1	0	9	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
10-245	M	1914	1978	67	1941	104	1972	0	B6	0.0	Z9C	0	0	0	0
10-247	M	1915	1976	07	1948	364	1972	1	B6	0.0	Z9C	0	0	1	0
10-249	M	1943		07	1962	126	1973	1	B6	0.0	Z9C	0	0	0	0
10-250	F	1938		07	1956	23	1982	0	B6	0.0	Z9C	0	0	0	0
10-251	F	1923		01	1941	65	1974	2	B3	0.0	Z9C	0	0	5	0
10-252	F	1919		01	1935	273	1982	5	B2	0.0	Z9C	1	0	18	0
10-254	F	1905		07	1953	832	1976	0	B6	0.0	Z9C	0	0	0	0
10-256	F	1917		01	1940	78	1972	1	B6	0.0	Z9B	0	0	3	0
10-257	F	1932		07	1951	56	1982	1	B6	0.0	Z9C	0	0	1	0
10-258	F	1923		01	1943	26	1972	3	B6	0.0	Z9C	1	0	8	0
10-260	F	1913		01	1928	52	1978	2	C6	0.0	Z9C	1	0	8	0
10-261	F	1922		01	1941	28	1972	3	B6	0.0	Z9C	1	0	8	0
10-262	F	1919		01	1941	104	1973	2	B6	0.0	Z9C	0	0	5	0
10-263	F	1921		01	1941	130	1972	2	B6	0.0	Z9B	0	0	6	0
10-266	F	1905		01	1926	2236	1978	1	C6	0.0	Z9C	0	0	3	0
10-269	F	1925		01	1945	17	1972	0	B6	0.0	Z9C	0	0	0	0
10-270	F	1926		71	1946	104	1972	1	B6	0.0	Z9C	0	0	1	0
10-272	F	1915		01	1935	60	1979	5	C3	0.0	Z9C	2	0	20	0
10-273	F	1929		01	1948	22	1973	2	B6	0.0	Z9C	0	0	4	0
10-274	F	1924		01	1947	62	1973	3	B3	0.0	Z9C	1	0	8	0
10-276	F	1932		01	1951	6	1973	1	B6	0.0	Z9C	0	0	1	0
10-277	F	1915	1981	71	1946	154	1973	1	B6	0.0	Z9C	0	0	1	0
10-278	F	1908		71	1929	1872	1981	2	C6	0.0	Z9C	0	0	4	0
10-279	F	1937		01	1955	728	1973	2	B6	0.0	Z9C	0	0	2	0
10-280	F	1904		07	1921	1768	1981	1	C6	0.0	Z9C	0	0	2	0
10-281	F	1931		01	1950	416	1973	1	B6	0.0	Z9C	0	0	1	0
10-282	F	1921	1974	01	1941	22	1974	2	C6	0.0	Z9C	0	0	5	0
10-283	F	1918		01	1937	208	1974	0	B6	0.0	Z9C	0	0	1	0
10-284	F	1918		71	1936	1456	1974	3	B3	0.0	Z9C	1	0	6	0
10-285	M	1917		07	1935	81	1973	0	G6	0.0	Z9	0	0	0	0
10-286	F	1937		07	1956	124	1973	0	B6	0.0	Z9C	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
10-287	F	1923		01	1944	2	1973	1	B6	0.0	Z9C	0	0	3	0
10-291	F	1916		01	1934	104	1981	2	C6	0.0	Z9C	1	0	7	0
10-292	F	1913	1975	01	1934	102	1973	6	B3	0.0	Z9C	2	0	20	0
10-293	F	1938		07	1970	24	1973	0	B6	0.0	Z9C	0	0	0	0
10-294	F	1916		01	1934	416	1974	2	B6	0.0	Z9C	0	0	5	0
10-295	M	1923		07	1946	282	1973	2	B6	0.0	Z9C	0	0	2	0
10-296	F	1930		01	1948	50	1973	0	B6	0.0	Z9C	0	0	0	0
10-297	F	1929	1973	07	1969	66	1973	0	B6	0.0	Z9C	0	0	0	0
10-299	F	1923		01	1942	43	1973	6	B3	0.0	Z9C	2	0	18	0
10-300	F	1911		01	1940	1612	1977	0	B6	0.0	Z9C	0	0	1	0
10-301	M	1930		07	1948	74	1973	0	B6	0.0	Z9C	0	0	0	0
10-302	F	1917		07	1933	312	1973	0	B6	0.0	Z9C	0	0	0	0
10-304	F	1926		01	1950	364	1973	2	B6	0.0	Z9C	0	0	4	0
10-306	F	1907		01	1923	4	1981	4	C3	0.0	Z9C	1	0	22	0
10-307	F	1893	1948	05	1930	+0	1974	85	A2	0.0	Z9A	15	0	109	0
10-309	F	1925		01	1943	28	1973	2	B6	0.0	Z9C	0	0	5	0
10-310	F	1916		01	1935	53	1973	2	B6	0.0	Z9C	0	0	6	0
10-311	F	1919		01	1942	16	1973	0	B6	0.0	Z9C	0	0	1	0
10-312	F	1923		01	1942	16	1973	2	B6	0.0	Z9C	0	0	5	0
10-313	F	1924		01	1942	202	1973	9	B3	0.0	Z9C	2	0	24	0
10-314	F	1918		01	1943	119	1973	4	B3	0.0	Z9C	1	0	10	0
10-316	M	1946		07	1965	167	1973	2	B6	0.0	Z9C	0	0	1	0
10-318	M	1908		07	1970	364	1977	0	C6	0.0	Z9C	0	0	0	0
10-319	F	1912		07	1934	832	1973	6	B3	0.0	Z9C	1	0	17	0
10-320	M	1918		07	1939	1352	1973	1	B6	0.0	Z9C	0	0	2	0
10-321	F	1910		01	1942	1456	1981	0	C6	0.0	Z9C	0	0	0	0
10-322	F	1904		07	1936	1768	1981	2	C6	0.0	Z9C	0	0	3	0
10-323	F	1951		07	1973	52	1979	2	B3	0.0	Z9C	0	0	1	0
10-324	F	1912		01	1926	13	1978	0	C6	0.0	Z9C	0	0	0	0
10-325	M	1952		07	1970	22	1974	1	B6	0.0	Z9	0	0	0	0
10-326	F	1954		07	1973	39	1974	0	B6	0.0	Z9C	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
10-327	M	1953		07	1973	52	1977	1	C6	0.0	Z9C	0	0	0	0
10-329	F	1914		07	1938	884	1979	0	C6	0.0	Z9C	0	0	0	0
10-330	F	1921		07	1945	520	1973	0	B6	0.0	Z9C	0	0	0	0
10-331	F	1911		07	1934	162	1981	2	C6	0.0	Z9C	1	0	8	0
10-332	F	1901		01	1927	0	1978	0	G6	0.00204	Z8	0	0	0	0
10-333	F	1915		01	1941	208	1973	1	B6	0.0	Z9B	0	0	3	0
10-334	F	1921		01	1943	26	1973	0	B6	0.0	Z9B	0	0	0	0
10-335	F	1939		07	1969	24	1973	0	B6	0.0	Z9C	0	0	0	0
10-336	F	1923		07	1943	1092	1973	0	B6	0.0	Z9C	0	0	0	0
10-337	M	1892	1971	06	1913	260	1974	1	A6	0.0	Z9A	0	0	2	0
10-339	F	1902		01	1925	1	1976	0	B6	0.00260	Z8	0	0	0	0
10-340	F	1920		67	1942	104	1974	6	B3	0.0	Z9B	1	0	17	0
10-341	F	1919		01	1939	312	1973	1	B6	0.0	Z9B	0	0	3	0
10-347	M	1947		08	1947	39	1973	1	B6	0.0	Z9B	0	0	2	0
10-348	F	1921		01	1941	104	1974	0	B6	0.0	Z9C	0	0	0	0
10-350	F	1924		01	1941	27	1973	1	B6	0.0	Z9C	0	0	3	0
10-351	M	1931		07	1964	14	1973	1	B6	0.0	Z9C	0	0	1	0
10-352	F	1926		07	1947	104	1974	1	B6	0.0	Z9C	0	0	2	0
10-353	F	1922		01	1942	21	1973	1	B6	0.0	Z9C	0	0	1	0
10-356	F	1915		07	1948	46	1980	1	C6	0.0	Z9C	0	0	3	0
10-357	F	1923		01	1942	68	1973	3	B3	0.0	Z9C	1	0	9	0
10-358	F	1920		01	1946	16	1973	3	B3	0.0	Z9C	1	0	7	0
10-359	M	1950		07	1971	32	1973	3	B3	0.0	Z9C	0	0	1	0
10-360	F	1919		01	1941	46	1975	0	B6	0.0	Z9B	0	0	0	0
10-362	F	1922		01	1941	364	1973	4	B3	0.0	Z9C	1	0	11	0
10-365	F	1920		01	1939	260	1973	0	B6	0.0	Z9C	0	0	1	0
10-367	F	1919		01	1940	260	1973	1	B6	0.0	Z9C	0	0	2	0
10-369	F	1921	1982	01	1941	104	1978	1	C6	0.0	Z9C	0	0	2	0
10-370	F	1916		01	1934	312	1981	1	B3	0.0	Z9C	0	0	4	0
10-375	F	1924		01	1943	20	1973	1	B6	0.0	Z9C	0	0	3	0
10-377	F	1898		07	1923	1976	1981	0	C6	0.0	Z9C	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
10-378	F	1906		07	1946	520	1981	0	C6	0.0	Z9C	0	0	0	0
10-379	F	1917		01	1941	89	1983	21	B1	0.0	Z9C	6	0	69	0
10-381	F	1927		01	1946	27	1973	6	B3	0.0	Z9C	1	0	14	0
10-382	F	1923		01	1942	119	1973	5	B3	0.0	Z9C	1	0	15	0
10-384	F	1919		71	1943	884	1973	1	B6	0.0	Z9C	0	0	3	0
10-385	F	1921		07	1964	16	1973	0	B6	0.0	Z9C	0	0	0	0
10-386	F	1933		01	1954	56	1973	1	B6	0.0	Z9C	0	0	2	0
10-387	F	1928		01	1947	15	1973	0	B6	0.0	Z9C	0	0	0	0
10-388	F	1927		01	1945	51	1983*	0	B6	0.0	Z9C	0	0	0	0
10-389	F	1919		01	1943	24	1973	0	B6	0.0	Z9C	0	0	0	0
10-390	F	1923		01	1942	38	1973	3	B3	0.0	Z9C	1	0	9	0
10-392	F	1903		07	1932	520	1973	0	B6	0.0	Z9C	0	0	0	0
10-393	F	1907		01	1925	208	1981	1	C6	0.0	Z9C	0	0	6	0
10-394	F	1907	1976	01	1923	728	1974	1	B6	0.0	Z9C	0	0	2	0
10-395	F	1908		01	1925	260	1981	0	C6	0.0	Z9C	0	0	0	0
10-397	F	1927		01	1946	16	1973	1	B6	0.0	Z9C	0	0	2	0
10-398	F	1918		71	1951	624	1973	1	B6	0.0	Z9C	0	0	1	0
10-409	F	1921		01	1943	118	1973	0	B6	0.0	Z9C	0	0	0	0
10-410	F	1926		01	1946	5	1973	0	B6	0.0	Z9C	0	0	0	0
10-411	F	1920	1981	01	1942	14	1973	3	B3	0.0	Z9C	1	0	8	0
10-412	F	1908		01	1925	13	1976	1	B6	0.0	Z9C	0	0	3	0
10-414	F	1926		01	1944	511	1973	1	B6	0.0	Z9C	0	0	3	0
10-415	F	1943		07	1973	8	1974	0	B6	0.0	Z9C	0	0	0	0
10-416	F	1953		01	1972	290	1979	0	B6	0.0	Z9C	0	0	0	0
10-419	M	1913		06	1936	2184	1978	2	C6	0.0	Z9C	0	0	2	0
10-432	F	1920		01	1940	104	1975	0	B6	0.0	Z9C	0	0	1	0
10-438	F	1907		01	1925	17	1977	14	C6	0.0	Z9	4	0	64	0
10-439	F	1925		01	1943	20	1973	2	B6	0.0	Z9C	0	0	6	0
10-440	F	1920		01	1948	1	1973	0	B6	0.0	Z9C	0	0	0	0
10-442	F	1932		01	1951	8	1973	0	B6	0.0	Z9C	0	0	0	0
10-443	F	1899		01	1926	234	1979	34	G4	0.0	Z9	10	0	153	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
10-444	F	1927		01	1949	4	1973	1	B6	0.0	Z9C	0	0	1	0
10-445	F	1924		01	1943	2	1973	2	B6	0.0	Z9C	0	0	6	0
10-446	F	1920		01	1940	3	1973	1	B6	0.0	Z9C	0	0	2	0
10-447	F	1929		01	1947	5	1973	6	B3	0.0	Z9C	1	0	14	0
10-449	F	1923		01	1943	0	1976	4	B2	0.0	Z9C	1	0	11	0
10-451	F	1921		01	1943	3	1973	0	B6	0.0	Z9C	0	0	1	0
10-453	F	1927		01	1943	1	1973	0	B6	0.0	Z9C	0	0	1	0
10-454	F	1926		01	1942	5	1973	0	B6	0.0	Z9C	0	0	1	0
10-455	F	1909		01	1928	104	1977	0	B6	0.0	Z9C	0	0	1	0
10-457	F	1921		01	1941	65	1973	1	B6	0.0	Z9C	0	0	4	0
10-458	M	1927		01	1954	1040	1973	24	B2	0.0	Z9C	2	0	11	0
10-459	F	1923		01	1956	832	1973	0	B6	0.0	Z9C	0	0	0	0
10-460	F	1936		01	1959	676	1973	0	B6	0.0	Z9C	0	0	0	0
10-464	M	1940		07	1961	12	1973	0	B6	0.0	Z9C	0	0	0	0
10-465	F	1924		01	1942	8	1973	0	B6	0.0	Z9C	0	0	0	0
10-470	F	1924		01	1942	179	1973	0	B6	0.0	Z9C	0	0	0	0
10-471	F	1924		01	1943	34	1973	3	B3	0.0	Z9C	1	0	8	0
10-472	F	1928		01	1947	12	1973	0	B6	0.0	Z9C	0	0	0	0
10-473	F	1926		01	1945	18	1973	0	B6	0.0	Z9C	0	0	1	0
10-474	F	1921		01	1946	77	1974	2	B6	0.0	Z9C	0	0	5	0
10-475	F	1927		07	1946	90	1973	0	B6	0.0	Z9C	0	0	0	0
10-476	F	1928		01	1946	12	1973	1	B6	0.0	Z9C	0	0	1	0
10-477	F	1924		01	1944	42	1975	2	B3	0.0	Z9C	1	0	7	0
10-478	F	1922		01	1942	11	1973	0	B6	0.0	Z9C	0	0	0	0
10-479	F	1926		01	1946	11	1973	0	B6	0.0	Z9C	0	0	0	0
10-480	F	1924		01	1943	4	1973	0	B6	0.0	Z9C	0	0	1	0
10-481	F	1925		01	1942	5	1973	1	B6	0.0	Z9C	0	0	3	0
10-482	F	1925		01	1943	28	1973	4	B3	0.0	Z9C	1	0	12	0
10-483	M	1934		07	1951	5	1973	2	B6	0.0	Z9C	0	0	2	0
10-485	F	1918		01	1948	4	1973	0	B6	0.0	Z9C	0	0	1	0
10-486	F	1919		01	1942	32	1973	0	B6	0.0	Z9C	0	0	1	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Skel. Rads ^{226}Ra	(16) Skel. Rads ^{228}Ra
10-487	F	1924		01	1943	220	1973	0	B6	0.0	Z9C	0	0	1	0
10-488	F	1921		01	1942	20	1973	0	B6	0.0	Z9C	0	0	0	0
10-490	F	1922		01	1943	20	1974	8	B2	0.0	Z9C	2	0	22	0
10-492	F	1925	1981	01	1951	326	1973	2	B6	0.0	Z9C	0	0	3	0
10-494	F	1913		01	1939	312	1973	1	B6	0.0	Z9C	0	0	2	0
10-495	F	1924		01	1942	312	1973	0	B6	0.0	Z9B	0	0	0	0
10-496	F	1922		01	1940	108	1975	0	B6	0.0	Z9C	0	0	0	0
10-501	F	1928		01	1946	15	1973	2	B6	0.0	Z9C	0	0	4	0
10-502	F	1928		01	1946	13	1973	2	B6	0.0	Z9C	0	0	5	0
10-505	F	1933		01	1951	3	1973	2	B6	0.0	Z9C	0	0	4	0
10-506	F	1920		07	1946	4	1973	0	B6	0.0	Z9C	0	0	1	0
10-510	F	1924		07	1942	26	1973	1	B6	0.0	Z9C	0	0	3	0
10-511	F	1923		01	1943	12	1973	5	B3	0.0	Z9C	1	0	14	0
10-512	F	1936		01	1965	1	1973	0	B6	0.0	Z9C	0	0	0	0
10-518	F	1905		06	1928	1196	1978	1	B6	0.0	Z9B	0	0	3	0
10-520	F	1924		01	1942	5	1973	1	B6	0.0	Z9C	0	0	3	0
10-521	F	1923		01	1955	416	1973	1	B6	0.0	Z9C	0	0	2	0
10-523	F	1922		01	1942	17	1973	0	B6	0.0	Z9C	0	0	0	0
10-525	F	1928		01	1947	1	1973	1	B6	0.0	Z9C	0	0	2	0
10-530	F	1952		07	1971	52	1973	3	B6	0.0	Z9C	0	0	1	0
10-531	F	1924		01	1946	1	1973	2	B6	0.0	Z9C	0	0	5	0
10-532	F	1916		01	1942	2	1973	1	B6	0.0	Z9C	0	0	3	0
10-533	F	1925		01	1943	5	1973	2	B6	0.0	Z9C	0	0	5	0
10-534	F	1925		01	1946	54	1973	2	C6	0.0	Z9C	0	0	5	0
10-535	F	1927		01	1946	16	1973	1	C6	0.0	Z9C	0	0	2	0
10-536	F	1927		01	1942	1	1973	1	B6	0.0	Z9C	0	0	3	0
10-538	M	1896	1978	07	1938	2028	1977	1	B2	0.0	Z9C	0	0	1	0
10-540	M	1917	1978	01	1939	1768	1973	2	B6	0.0	Z9C	0	0	1	0
10-543	M	1891		06	1916	26	1973	3	B3	0.0	Z9B	1	0	12	0
10-546	F	1906		07	1929	208	1979	6	C3	0.0	Z9C	2	0	24	0
10-549	F	1919		01	1941	62	1973	4	B3	0.0	Z9C	1	0	13	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
10-550	F	1914		17	1965	230	1979	1	C6	0.0	Z9C	0	0	1	0
10-557	F	1921		01	1942	43	1974	4	B3	0.0	Z9C	1	0	11	0
10-558	M	1927		07	1951	40	1973	5	B3	0.0	Z9C	1	0	7	0
10-559	F	1919		01	1941	69	1973	2	B6	0.0	Z9C	0	0	5	0
10-560	F	1923		01	1942	96	1973	4	B3	0.0	Z9C	1	0	10	0
10-561	M	1906		06	1927	52	1978	2	B6	0.0	Z9B	1	0	6	0
10-566	M	1914	1977	02	1930	13	1976	5	B2	0.00334	Z5B	1	1	14	14
10-567	F	1913		06	1931	572	1963	2	G6	0.0	Z9	0	0	4	0
10-569	F	1925		01	1946	1	1975	0	B6	0.0	Z9C	0	0	0	0
10-570	M	1907		06	1934	780	1977	2	B3	0.0	Z9C	0	0	4	0
10-573	F	1922		01	1944	14	1973	3	B3	0.0	Z9C	1	0	7	0
10-574	M	1908		61	1930	2236	1980	2	C6	0.0	Z9C	0	0	4	0
10-575	F	1930		01	1948	1040	1973	4	B3	0.0	Z9C	1	0	5	0
10-582	F	1938		01	1965	416	1973	1	B6	0.0	Z9C	0	0	0	0
10-583	M	1918		06	1939	1352	1973	0	B6	0.0	Z9C	0	0	0	0
10-584	F	1925		01	1942	3	1973	1	B6	0.0	Z9C	0	0	2	0
10-585	M	1908		06	1930	52	1978	1	C6	0.0	Z9C	0	0	4	0
10-587	M	1946		07	1966	416	1973	1	B6	0.0	Z9C	0	0	0	0
10-588	F	1910		01	1927	2	1974	0	G6	0.00330	Z8	0	0	0	0
10-589	M	1938		07	1971	78	1973	2	B3	0.0	Z9C	0	0	0	0
10-590	M	1912	1979	06	1948	728	1979	0	B6	0.0	Z9B	0	0	0	0
10-592	M	1899		06	1923	1300	1978	1	B6	0.0	Z9B	0	0	3	0
10-594	F	1917		01	1943	5	1973	5	B3	0.0	Z9C	1	0	14	0
10-595	F	1908		01	1928	104	1977	6	C6	0.0	Z9	2	0	25	0
10-596	F	1909		01	1927	6	1973	6	B3	0.0	Z9C	2	0	24	0
10-597	F	1911		01	1928	17	1976	2	B3	0.0	Z9C	1	0	9	0
10-598	F	1914	1979	01	1934	156	1973	1	B6	0.0	Z9C	0	0	3	0
10-601	M	1920	1981	07	1951	0	1975	0	B6	0.0	Z9B	0	0	0	0
10-606	F	1910		07	1928	468	1975	0	B6	0.0	Z9B	0	0	0	0
10-608	F	1917		01	1939	14	1975	1	B6	0.0	Z9C	0	0	2	0
10-609	F	1925		01	1943	42	1973	2	B6	0.0	Z9C	0	0	4	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
10-610	F	1920		01	1941	22	1975	2	B3	0.0	Z9C	0	0	5	0
10-611	F	1924		01	1942	13	1973	2	B6	0.0	Z9C	0	0	6	0
10-613	F	1919		01	1945	12	1973	0	B6	0.0	Z9C	0	0	0	0
10-614	F	1915		01	1942	30	1975	1	B6	0.0	Z9C	0	0	3	0
10-616	F	1929		01	1948	15	1973	2	B6	0.0	Z9C	0	0	4	0
10-617	F	1922		01	1942	182	1974	10	B2	0.0	Z9C	2	0	28	0
10-618	F	1923		01	1944	54	1975	0	B6	0.0	Z9C	0	0	1	0
10-621	M	1905		06	1925	1716	1979	1	C6	0.0	Z9C	0	0	2	0
10-623	M	1917		06	1938	1144	1973	1	B6	0.0	Z9B	0	0	2	0
10-627	M	1911		07	1928	208	1974	4	G6	0.00420	Z5	1	1	12	11
10-628	M	1906		06	1927	156	1976	0	B6	0.0	Z9B	0	0	0	0
10-630	F	1915		01	1937	13	1981	0	C6	0.0	Z9C	0	0	0	0
10-631	F	1929		01	1946	26	1974	0	B6	0.0	Z9C	0	0	0	0
10-635	F	1922		01	1943	156	1973	3	B6	0.0	Z9C	1	0	7	0
10-643	M	1853	1928	05	1928	0	1978	316	A1	0.0	Z9	4	0	1	0
10-644	M	1870	1927	05	1927	0	1975	5300	A1	0.0	Z9	30	0	3	0
10-645	F	1930		76	1948	90	1973	0	B6	0.0	Z9C	0	0	0	0
10-648	F	1923		01	1942	30	1974	2	B6	0.0	Z9C	0	0	5	0
10-649	F	1921		01	1942	15	1973	2	B6	0.0	Z9C	0	0	5	0
10-650	F	1926		01	1946	59	1973	8	B2	0.0	Z9C	2	0	19	0
10-651	F	1923		01	1942	260	1974	0	B6	0.0	Z9C	0	0	0	0
10-653	F	1926	1979	01	1946	16	1973	0	B6	0.0	Z9C	0	0	0	0
10-655	F	1922		01	1947	2	1978	2	C6	0.0	Z9C	1	0	6	0
10-656	F	1923		01	1942	20	1973	1	B6	0.0	Z9C	0	0	2	0
10-657	F	1922	1976	01	1943	13	1973	1	B6	0.0	Z9C	0	0	3	0
10-658	F	1906		01	1927	208	1974	6	B2	0.0	Z9C	2	0	25	0
10-659	F	1904	1980	01	1927	52	1974	0	B6	0.0	Z9C	0	0	2	0
10-660	F	1924		01	1942	172	1973	18	B2	0.0	Z9C	4	0	49	0
10-661	F	1926	1973	01	1945	23	1977	10	F5	0.0	Z9	2	0	21	0
10-662	F	1909		01	1930	13	1977	2	B3	0.0	Z9C	1	0	10	0
10-664	F	1925		01	1943	1	1973	3	B3	0.0	Z9C	1	0	8	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
10-665	F	1927		01	1946	104	1973	1	B6	0.0	Z9C	0	0	3	0
10-666	F	1924		01	1943	13	1974	1	B6	0.0	Z9C	0	0	2	0
10-667	F	1908	1974	01	1925	52	1973	7	B2	0.0	Z9C	2	0	26	0
10-668	F	1925		01	1943	19	1973	1	B6	0.0	Z9C	0	0	2	0
10-671	M	1932		06	1957	988	1982	1	B3	0.0	Z9C	0	0	1	0
10-672	M	1916	1980	06	1936	1040	1974	0	B6	0.0	Z9B	0	0	0	0
10-673	M	1911	1976	06	1932	364	1973	0	B6	0.0	Z9B	0	0	0	0
10-675	F	1921		04	1929	26	1982	4	B2	0.0	Z9C	1	0	17	0
10-681	M	1922		07	1941	1508	1982	1	B6	0.0	Z9C	0	0	1	0
10-683	F	1924		01	1942	14	1973	0	B6	0.0	Z9C	0	0	0	0
10-684	M	1927		07	1950	104	1974	1	B6	0.0	Z9C	0	0	2	0
10-688	F	1923	1976	01	1942	12	1974	4	B2	0.0	Z9C	1	0	11	0
10-689	F	1919	1982	01	1943	26	1974	3	B3	0.0	Z9C	1	0	7	0
10-696	F	1911		01	1929	15	1977	8	G6	0.0	Z9	2	0	34	0
10-714	F	1908		01	1925	57	1979	1	B6	0.00126	Z4B	0	0	5	4
10-718	F	1910	1979	01	1925	0	1979	7	G4	0.0	Z9	2	0	32	0
10-723	F	1911		01	1929	15	1982	2	B3	0.0	Z9C	1	0	8	0
10-725	M	1927		07	1952	1	1973	5	B2	0.0	Z9C	1	0	7	0
10-728	F	1923		01	1946	2	1974	0	B6	0.0	Z9C	0	0	0	0
10-729	F	1902		06	1920	832	1973	1	B6	0.0	Z9B	0	0	4	0
10-730	F	1907		01	1928	260	1979	1	C6	0.0	Z9C	0	0	4	0
10-731	M	1921		07	1951	1196	1974	2	B3	0.0	Z9C	0	0	1	0
10-732	M	1924		07	1950	1300	1974	0	B6	0.0	Z9C	0	0	0	0
10-736	F	1929		01	1948	9	1974	0	B6	0.0	Z9C	0	0	0	0
10-738	M	1923		07	1965	6	1974	3	B3	0.0	Z9C	0	0	2	0
10-739	F	1931		01	1951	7	1974	1	B6	0.0	Z9C	0	0	1	0
10-741	F	1927		01	1945	60	1977	1	B6	0.0	Z9C	0	0	3	0
10-742	F	1929		07	1946	1	1974	2	B3	0.0	Z9C	0	0	4	0
10-744	F	1890	1978	05	1925	0	1975	120	G4	0.0	Z9	37	0	523	0
10-754	F	1881	1977	05	1925	0	1975	12	G4	0.0	Z9	4	0	52	0
10-786	F	1866	1928	05	1927	0	1976	1360	A4	0.0	Z9	40	0	38	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
10-807	M	1894	1976	05	1925	1	1976	388	B1	0.0	Z9B	119	0	1190	0
10-825	M	1904		05	1927	0	1978	941	B1	0.0	Z9B	289	0	3070	0
10-831	M	1879	1926	05	1925	+0	1977	786	A1	0.0	Z9	36	0	39	0
10-840	M	1869	1926	05	1925	0	1976	390	A1	0.0	Z9	9	0	5	0
10-850	F	1925		01	1943	0	1974	1	B6	0.0	Z9C	0	0	3	0
10-851	F	1921		01	1951	139	1974	0	B6	0.0	Z9B	0	0	0	0
10-852	F	1905	1980	01	1923	13	1974	0	B6	0.01300	Z2B	0	0	0	0
10-853	F	1919		17	1947	1300	1974	1	B6	0.0	Z9B	0	0	1	0
10-854	M	1909		06	1928	104	1979	1	B6	0.0	Z9B	0	0	3	0
10-855	F	1928		01	1946	28	1976	7	B2	0.0	Z9C	2	0	17	0
10-856	F	1952		01	1973	6	1974	1	B6	0.0	Z9C	0	0	0	0
10-859	F	1951		07	1973	0	1974	0	B6	0.0	Z9C	0	0	0	0
10-860	F	1925		07	1962	7	1974	7	B2	0.0	Z9C	1	0	8	0
10-861	F	1954		01	1973	22	1974	1	B6	0.0	Z9C	0	0	0	0
10-862	F	1928		01	1946	10	1974	0	B6	0.0	Z9C	0	0	0	0
10-864	M	1906		01	1949	1560	1979	0	C6	0.0	Z9C	0	0	0	0
10-866	F	1900		01	1920	12	1979	8	G4	0.00775	Z2	3	26	42	398
10-867	F	1915		07	1929	209	1974	0	B6	0.0	Z9B	0	0	0	0
10-869	F	1902		01	1927	132	1979	2	C6	0.00181	Z8B	1	1	9	8
10-870	F	1911	1978	07	1944	650	1974	0	B6	0.0	Z9B	0	0	0	0
10-874	F	1924		01	1942	728	1974	4	B3	0.0	Z9B	1	0	9	0
10-880	M	1912		06	1935	156	1974	0	B6	0.0	Z9B	0	0	0	0
10-883	F	1883	1935	02	1930	+0	1975	27	A1	0.0	Z9	2	0	8	0
10-890	F	1912		01	1927	2	1979	0	B6	0.00181	Z8B	0	0	0	0
10-893	F	1926		01	1943	78	1977	5	B2	0.0	Z9C	1	0	15	0
10-894	F	1924		01	1942	38	1974	1	B6	0.0	Z9C	0	0	2	0
10-895	F	1925		01	1943	9	1974	2	B3	0.0	Z9C	0	0	4	0
10-896	F	1923		01	1941	8	1974	0	B6	0.0	Z9C	0	0	1	0
10-897	F	1930		07	1951	208	1975	3	B6	0.0	Z9C	1	0	5	0
10-901	F	1910		01	1924	3	1975	0	B6	0.01160	Z2B	0	0	0	0
10-902	M	1905		06	1928	17	1982	0	B6	0.0	Z9C	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
10-903	F	1909		01	1943	2	1976	0	B6	0.0	Z9C	0	0	1	0
10-905	F	1928		01	1946	10	1974	0	B6	0.0	Z9C	0	0	1	0
10-906	F	1921	1980	07	1969	0	1976	1	B6	0.0	Z9C	0	0	0	0
10-907	F	1910		01	1946	5	1979	1	C6	0.0	Z9C	0	0	2	0
10-908	F	1928		01	1946	4	1974	1	B6	0.0	Z9C	0	0	3	0
10-909	F	1919		01	1941	4	1974	2	B3	0.0	Z9C	1	0	7	0
10-911	F	1928		01	1947	2	1974	2	B6	0.0	Z9C	0	0	4	0
10-915	F	1931		01	1953	0	1974	1	B6	0.0	Z9C	0	0	1	0
10-916	F	1915		01	1946	2	1974	0	B6	0.0	Z9C	0	0	0	0
10-918	F	1907		01	1923	0	1981	2	C6	0.00547	Z2C	1	3	8	50
10-919	F	1924		01	1943	8	1974	2	B6	0.0	Z9C	0	0	4	0
10-920	F	1929		01	1947	4	1977	0	C6	0.0	Z9C	0	0	0	0
10-921	F	1905		01	1923	1	1977	0	G6	0.00907	Z2	0	0	0	0
10-928	M	1918		07	1948	0	1958	1	G6	0.0	Z9	0	0	1	0
10-931	M	1911		01	1946	1040	1979	4	C3	0.0	Z9C	1	0	6	0
10-932	M	1903		76	1919	208	1979	15	B2	0.0	Z9B	5	0	56	0
10-933	F	1924		01	1943	3	1974	2	B6	0.0	Z9C	0	0	6	0
10-938	F	1952		01	1971	8	1974	0	B6	0.0	Z9C	0	0	0	0
10-940	F	1939		07	1958	4	1974	1	B6	0.0	Z9C	0	0	1	0
10-941	F	1928		01	1948	13	1974	1	B6	0.0	Z9C	0	0	1	0
10-944	F	1922		01	1951	6	1974	0	B6	0.0	Z9C	0	0	0	0
10-945	F	1915		01	1943	12	1979	4	C3	0.0	Z9C	1	0	12	0
10-948	F	1923		01	1943	3	1974	0	B6	0.0	Z9C	0	0	1	0
10-949	F	1925		01	1943	0	1974	2	B3	0.0	Z9C	0	0	6	0
10-950	F	1922		01	1943	1	1974	5	B2	0.0	Z9C	1	0	13	0
10-951	F	1916		01	1943	4	1980	2	C6	0.0	Z9C	1	0	7	0
10-952	F	1911		01	1927	10	1980	1	C6	0.00160	Z8C	0	0	6	6
10-953	F	1908		01	1923	49	1979	15	G6	0.00770	Z2	5	32	75	478
10-955	F	1922		01	1942	104	1974	1	B6	0.0	Z9B	0	0	3	0
10-957	F	1922		01	1941	130	1974	1	B6	0.0	Z9B	0	0	3	0
10-958	F	1931		01	1951	13	1975	3	B3	0.0	Z9C	1	0	7	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
10-959	F	1923		01	1946	2	1974	4	B3	0.0	Z9C	1	0	9	0
10-962	F	1916		07	1934	27	1978	0	B6	0.0	Z9B	0	0	0	0
10-963	F	1901		01	1919	10	1975	647	B1	0.00170	C3	209	318	3381	4784
10-966	F	1908		01	1929	4	1974	0	B6	0.0	Z9B	0	0	0	0
10-967	F	1924		01	1943	2	1974	0	B6	0.0	Z9C	0	0	0	0
10-969	M	1920	1981	07	1969	52	1976	0	B6	0.0	Z9C	0	0	0	0
10-970	F	1955		07	1973	22	1974	2	B3	0.0	Z9C	0	0	0	0
10-971	F	1952		17	1973	22	1975	1	B6	0.0	Z9C	0	0	0	0
10-972	F	1926		01	1947	5	1974	0	B6	0.0	Z9C	0	0	1	0
10-974	F	1924		01	1941	48	1974	0	B6	0.0	Z9B	0	0	0	0
10-975	F	1929		01	1947	13	1974	0	B6	0.0	Z9C	0	0	0	0
10-977	F	1923		01	1943	38	1974	6	B2	0.0	Z9C	1	0	17	0
10-978	M	1927		07	1943	1612	1974	4	B3	0.0	Z9C	0	0	3	0
10-979	F	1925		01	1943	13	1974	1	B6	0.0	Z9C	0	0	2	0
10-980	F	1926		07	1945	1	1974	1	B6	0.0	Z9C	0	0	3	0
10-981	F	1928		07	1946	0	1974	0	B6	0.0	Z9C	0	0	0	0
10-987	F	1926		01	1946	26	1974	1	B6	0.0	Z9C	0	0	4	0
10-988	M	1952	1974	07	1973	22	1974	0	B6	0.0	Z9C	0	0	0	0
10-989	F	1927		07	1958	3	1975	1	B6	0.0	Z9C	0	0	1	0
10-990	F	1920		07	1943	20	1974	0	B6	0.0	Z9C	0	0	0	0
10-991	M	1901		07	1941	1716	1979	2	C6	0.0	Z9C	0	0	3	0
10-992	F	1919		01	1942	39	1974	0	B6	0.0	Z9C	0	0	0	0
10-993	F	1904	1981	07	1942	4	1979	3	C3	0.0	Z9C	1	0	9	0
10-996	F	1900		07	1943	260	1979	1	B6	0.0	Z9B	0	0	3	0
10-997	F	1926		07	1945	572	1979	0	B6	0.0	Z9	0	0	0	0
10-998	F	1909		07	1942	988	1978	0	B6	0.0	Z9B	0	0	0	0
11-002	F	1919		01	1941	728	1979	0	B6	0.0	Z9	0	0	0	0
11-003	F	1919		07	1942	+0	1974	3	G6	0.0	Z9	1	0	9	0
11-004	M	1924		01	1946	702	1979	1	B6	0.0	Z9	0	0	2	0
11-005	M	1926		17	1948	1612	1979	3	B6	0.0	Z9	0	0	2	0
11-009	F	1913		07	1942	884	1979	0	B6	0.0	Z9B	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
11-010	F	1922		07	1942	598	1979	0	B6	0.0	Z9	0	0	0	0
11-015	F	1907		01	1925	2	1976	0	G6	0.01000	Z2	0	0	0	0
11-016	F	1906		01	1924	17	1978	24	C3	0.00803	Z2	8	43	117	642
11-017	F	1906		01	1923	1	1977	0	G6	0.00907	Z2	0	0	0	0
11-018	F	1908	1981	01	1925	5	1974	0	B6	0.00330	Z8B	0	0	0	0
11-021	F	1907		07	1931	282	1978	0	C6	0.00203	Z8	0	0	0	0
11-023	F	1911		17	1927	2	1975	0	B6	0.00290	Z8B	0	0	0	0
11-026	F	1916		01	1941	52	1981	0	C6	0.0	Z9C	0	0	0	0
11-027	F	1910	1979	71	1948	312	1978	0	B6	0.0	Z9	0	0	0	0
11-028	F	1925		01	1944	78	1974	0	B6	0.0	Z9B	0	0	0	0
11-030	F	1928		07	1951	112	1975	0	B6	0.0	Z9B	0	0	0	0
11-032	M	1931		06	1956	936	1974	3	B3	0.0	Z9C	0	0	1	0
11-033	M	1951		06	1973	104	1975	0	B6	0.0	Z9C	0	0	0	0
11-034	M	1915		06	1934	2184	1977	51	B2	0.0	Z9C	8	0	54	0
11-035	M	1949		07	1973	60	1977	0	C6	0.0	Z9C	0	0	0	0
11-036	M	1914		67	1946	1716	1979	6	C3	0.0	Z9C	1	0	4	0
11-038	M	1914		07	1940	1456	1979	11	C3	0.0	Z9C	2	0	15	0
11-040	M	1915		67	1939	2132	1980	6	C3	0.0	Z9C	1	0	5	0
11-042	M	1923		06	1946	1456	1974	5	B3	0.0	Z9C	1	0	3	0
11-045	M	1915	1976	06	1943	1560	1974	27	B2	0.0	Z9C	4	0	18	0
11-049	F	1908		01	1923	13	1981	2	C6	0.00563	Z2C	1	4	10	63
11-053	F	1905		01	1923	0	1977	0	G6	0.00907	Z2	0	0	0	0
11-056	F	1908		01	1927	40	1974	2	B6	0.00330	Z8B	1	1	9	8
11-059	F	1925		01	1943	13	1974	0	B6	0.0	Z9B	0	0	0	0
11-065	F	1928		07	1943	13	1974	0	B6	0.0	Z9B	0	0	0	0
11-070	F	1924		01	1945	26	1974	1	B6	0.0	Z9	0	0	1	0
11-071	F	1935		07	1967	2	1974	2	B3	0.0	Z9C	0	0	1	0
11-081	M	1921		07	1941	1300	1978	1	C6	0.0	Z9C	0	0	2	0
11-086	F	1919		01	1941	208	1977	2	C6	0.0	Z9C	0	0	6	0
11-087	M	1923		07	1941	52	1977	3	C6	0.0	Z9C	1	0	7	0
11-089	F	1920	1980	01	1942	182	1978	2	C6	0.0	Z9C	1	0	6	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
11-092	F	1911		01	1943	52	1977	0	C6	0.0	Z9C	0	0	0	0
11-103	F	1918		01	1942	100	1980	2	B3	0.0	Z9C	0	0	5	0
11-104	F	1905		07	1942	43	1978	1	B6	0.0	Z9B	0	0	3	0
11-107	F	1916		01	1942	52	1977	0	B6	0.0	Z9C	0	0	1	0
11-108	F	1923		07	1941	208	1977	1	B6	0.0	Z9C	0	0	2	0
11-112	F	1916		01	1943	52	1977	1	B6	0.0	Z9C	0	0	2	0
11-115	F	1909		01	1942	104	1979	1	B6	0.0	Z9C	0	0	3	0
11-118	F	1920		01	1942	260	1979	0	B6	0.0	Z9C	0	0	0	0
11-119	F	1918		01	1941	117	1976	0	B6	0.0	Z9B	0	0	0	0
11-120	F	1919		01	1943	39	1979	1	C6	0.0	Z9C	0	0	2	0
11-121	F	1909		01	1950	520	1977	0	C6	0.0	Z9C	0	0	0	0
11-129	F	1923		17	1942	182	1978	0	C6	0.0	Z9C	0	0	0	0
11-131	F	1933		01	1952	104	1978	0	C6	0.0	Z9C	0	0	0	0
11-143	F	1923		01	1940	104	1977	0	C6	0.0	Z9C	0	0	1	0
11-147	F	1907		01	1943	52	1981	0	B6	0.0	Z9C	0	0	1	0
11-161	F	1921		01	1940	130	1976	0	B6	0.0	Z9B	0	0	0	0
11-166	F	1917		01	1942	137	1978	2	C6	0.0	Z9C	0	0	5	0
11-168	F	1918		01	1942	90	1979	0	B6	0.0	Z9B	0	0	0	0
11-173	F	1911	1980	07	1943	104	1980	0	C6	0.0	Z9C	0	0	0	0
11-176	F	1915		01	1942	208	1977	2	C6	0.0	Z9C	1	0	6	0
11-184	F	1919		01	1941	260	1978	2	C6	0.0	Z9C	0	0	6	0
11-190	F	1921		01	1942	156	1978	1	C6	0.0	Z9C	0	0	3	0
11-192	F	1924		07	1943	104	1977	1	B1	0.0	Z9C	0	0	3	0
11-196	F	1916	1982	67	1941	208	1977	1	B6	0.0	Z9C	0	0	2	0
11-207	M	1917		01	1939	208	1974	0	B6	0.0	Z9B	0	0	0	0
11-223	F	1917		07	1943	104	1978	2	C6	0.0	Z9C	0	0	5	0
11-230	F	1904		07	1942	104	1981	0	C6	0.0	Z9C	0	0	0	0
11-231	F	1912		01	1942	34	1980	0	B6	0.0	Z9C	0	0	0	0
11-232	F	1919		07	1942	156	1978	1	C6	0.0	Z9C	0	0	2	0
11-246	F	1916		07	1942	78	1977	1	B6	0.0	Z9C	0	0	2	0
11-247	F	1923		07	1944	104	1978	1	C6	0.0	Z9C	0	0	2	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
11-262	F	1913		01	1933	208	1981	1	C6	0.0	Z9C	0	0	5	0
11-264	F	1915		01	1934	130	1976	0	B6	0.0	Z9C	0	0	0	0
11-285	F	1915		07	1946	154	1980	0	C6	0.0	Z9C	0	0	0	0
11-290	F	1917		01	1946	412	1978	2	C6	0.0	Z9C	0	0	4	0
11-291	F	1919		17	1951	164	1974	3	B3	0.0	Z9C	1	0	5	0
11-293	M	1942		07	1965	15	1980	0	B6	0.0	Z9C	0	0	0	0
11-294	M	1943		07	1968	6	1974	0	B6	0.0	Z9C	0	0	0	0
11-296	M	1923		71	1961	156	1978	2	B6	0.0	Z9	0	0	2	0
11-302	F	1901		01	1924	0	1976	0	B6	0.01000	Z2B	0	0	0	0
11-304	F	1912	1982	07	1928	150	1978	0	B6	0.0	Z9B	0	0	0	0
11-329	F	1915	1981	17	1933	156	1978	0	C6	0.0	Z9	0	0	0	0
11-361	F	1910		01	1925	23	1982	2	B3	0.00126	Z8C	1	1	9	12
11-368	F	1910	1983	01	1927	1	1977	0	G6	0.00230	Z8	0	0	0	0
11-389	F	1908	1980	01	1924	7	1976	3	B3	0.01150	Z2B	1	6	14	89
11-411	F	1905	1982	17	1922	345	1979	33	B2	0.00713	Z2B	10	49	156	741
11-453	F	1923		01	1942	13	1976	0	B6	0.0	Z9B	0	0	0	0
11-521	F	1910		01	1927	4	1974	0	B6	0.00330	Z8C	0	0	0	0
11-531	F	1894	1978	01	1918	54	1977	7	G4	0.00134	Z5	2	4	36	57
11-534	F	1918		01	1941	52	1978	3	C3	0.0	Z9C	1	0	9	0
11-561	F	1910	1981	01	1925	2	1976	0	G6	0.00260	Z8	0	0	0	0
11-565	F	1911		01	1927	76	1974	2	B6	0.00330	Z8B	1	1	9	8
11-584	F	1904	1981	01	1922	15	1977	4	B6	0.0	Z9B	1	0	20	0
11-637	M	1902		06	1934	52	1975	0	B6	0.0	Z9B	0	0	0	0
11-803	F	1905		06	1942	13	1976	0	G6	0.0	Z9	0	0	0	0
11-859	F	1923		01	1941	208	1978	1	B6	0.0	Z9B	0	0	3	0
11-861	F	1922		01	1941	364	1977	0	B6	0.0	Z9B	0	0	0	0
11-863	F	1916		01	1942	52	1977	0	B6	0.0	Z9	0	0	0	0
11-865	F	1920		16	1952	260	1978	2	B6	0.0	Z9B	0	0	4	0
11-866	F	1907		17	1942	156	1977	0	B6	0.0	Z9B	0	0	0	0
11-867	F	1924		06	1945	76	1980	3	B2	0.0	Z9C	1	0	8	0
11-869	F	1915		01	1943	3	1981	1	B3	0.0	Z9C	0	0	3	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
11-871	F	1925		01	1940	276	1977	5	B3	0.0	Z9B	1	0	15	0
11-875	F	1923		01	1941	364	1977	1	B6	0.0	Z9B	0	0	3	0
11-916	F	1918		01	1941	108	1975	1	B6	0.0	Z9B	0	0	3	0
11-923	F	1924		01	1942	208	1976	1	B1	0.0	Z9C	0	0	2	0
11-924	F	1920		01	1941	104	1978	1	C1	0.0	Z9C	0	0	2	0
11-925	F	1920		01	1941	78	1975	0	B6	0.0	Z9B	0	0	0	0
11-938	F	1931		01	1951	56	1975	0	B6	0.0	Z9B	0	0	0	0
11-943	F	1924		01	1941	78	1981	1	B6	0.0	Z9C	0	0	3	0
11-947	F	1925		01	1947	260	1975	4	B3	0.0	Z9B	1	0	9	0
11-948	F	1917		01	1943	104	1981	0	C6	0.0	Z9C	0	0	0	0
11-949	F	1921		01	1941	78	1981	0	B6	0.0	Z9C	0	0	0	0
11-950	F	1925		07	1944	52	1981	0	C6	0.0	Z9C	0	0	0	0
11-957	F	1925		01	1942	78	1979	1	B6	0.0	Z9B	0	0	3	0
11-959	F	1912		01	1941	208	1982	0	B6	0.0	Z9C	0	0	1	0
11-960	F	1924		01	1942	31	1975	0	B6	0.0	Z9B	0	0	0	0
11-962	F	1922		01	1942	130	1979	0	B6	0.0	Z9B	0	0	0	0
11-964	F	1925		01	1945	52	1980	0	B6	0.0	Z9C	0	0	1	0
11-971	F	1923		01	1944	52	1979	0	B6	0.0	Z9B	0	0	0	0
11-973	F	1919		01	1950	108	1975	1	B6	0.0	Z9B	0	0	2	0
11-974	F	1917		01	1944	40	1977	0	B6	0.0	Z9B	0	0	0	0
11-978	F	1920		01	1942	82	1980	0	B6	0.0	Z9C	0	0	1	0
11-982	F	1922		01	1942	208	1976	0	B6	0.0	Z9B	0	0	0	0
11-989	F	1921		01	1943	35	1977	0	C6	0.0	Z9C	0	0	0	0
11-991	F	1924		01	1942	6	1976	2	B6	0.0	Z9B	1	0	6	0
11-993	F	1919		01	1944	104	1980	2	B3	0.0	Z9C	0	0	5	0
11-999	M	1907		17	1941	160	1980	0	G6	0.0	Z9	0	0	0	0
12-002	F	1918		01	1941	52	1976	0	B6	0.0	Z9B	0	0	0	0
12-008	F	1916		01	1943	52	1982	2	B3	0.0	Z9C	0	0	5	0
12-016	F	1919		01	1941	111	1977	0	B6	0.0	Z9B	0	0	0	0
12-022	F	1924		01	1942	156	1978	0	B6	0.0	Z9B	0	0	0	0
12-025	F	1924		01	1951	182	1975	1	B6	0.0	Z9C	0	0	2	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
12-026	F	1914		01	1942	166	1976	0	B6	0.0	Z9B	0	0	0	0
12-027	F	1916		01	1942	181	1981	5	B2	0.0	Z9C	1	0	15	0
12-033	F	1925		07	1950	52	1975	3	B3	0.0	Z9B	1	0	7	0
12-034	F	1931		01	1952	1456	1981	0	B6	0.0	Z9C	0	0	0	0
12-038	F	1923		01	1943	26	1980	0	B6	0.0	Z9C	0	0	0	0
12-040	F	1921		01	1942	156	1976	3	G6	0.0	Z9	1	0	9	0
12-041	F	1911		07	1943	52	1981	0	C6	0.0	Z9C	0	0	0	0
12-043	F	1921		01	1942	182	1978	2	B6	0.0	Z9B	1	0	6	0
12-045	F	1925		01	1942	160	1977	0	B6	0.0	Z9B	0	0	0	0
12-059	F	1920		01	1942	52	1980	0	B6	0.0	Z9C	0	0	1	0
12-061	F	1920		01	1942	182	1975	1	B6	0.0	Z9B	0	0	3	0
12-063	F	1916		07	1943	104	1981	0	B6	0.0	Z9C	0	0	1	0
12-064	F	1924		01	1942	156	1979	0	B6	0.0	Z9B	0	0	0	0
12-066	F	1918		07	1948	43	1981	0	C6	0.0	Z9C	0	0	0	0
12-073	F	1920		01	1942	104	1980	1	B6	0.0	Z9C	0	0	2	0
12-074	F	1923		01	1943	104	1977	1	B6	0.0	Z9B	0	0	3	0
12-075	F	1923		01	1941	208	1977	1	B6	0.0	Z9B	0	0	3	0
12-081	F	1913		01	1941	52	1981	0	B6	0.0	Z9C	0	0	0	0
12-083	F	1920		01	1943	104	1981	0	B6	0.0	Z9C	0	0	1	0
12-086	F	1925		07	1942	156	1977	2	B6	0.0	Z9B	0	0	6	0
12-088	F	1921		01	1942	52	1981	0	B6	0.0	Z9C	0	0	0	0
12-089	F	1928		01	1943	52	1974	0	B6	0.0	Z9B	0	0	0	0
12-094	F	1929		01	1946	4	1975	3	B6	0.0	Z9C	1	0	6	0
12-095	F	1927		01	1947	1	1974	0	B6	0.0	Z9C	0	0	1	0
12-096	F	1921		01	1946	22	1978	2	C6	0.0	Z9C	1	0	7	0
12-098	F	1930		01	1951	52	1974	1	B6	0.0	Z9C	0	0	1	0
12-099	F	1929	1982	07	1951	18	1976	0	B6	0.0	Z9C	0	0	0	0
12-102	F	1951		07	1972	0	1978	1	C6	0.0	Z9C	0	0	0	0
12-106	F	1921		01	1943	4	1980	0	C6	0.0	Z9C	0	0	0	0
12-108	F	1915		01	1942	23	1980	0	C6	0.0	Z9C	0	0	0	0
12-110	F	1927		01	1946	1	1976	0	B6	0.0	Z9C	0	0	1	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
12-111	F	1929		01	1947	19	1974	4	B3	0.0	Z9C	1	0	10	0
12-113	F	1915		01	1942	19	1980	1	C6	0.0	Z9C	0	0	2	0
12-115	F	1953		07	1972	52	1975	0	B6	0.0	Z9C	0	0	0	0
12-117	F	1914		01	1943	3	1979	0	C6	0.0	Z9C	0	0	0	0
12-118	F	1932		16	1954	2	1977	1	B3	0.0	Z9C	0	0	3	0
12-119	F	1938		17	1967	41	1975	1	B6	0.0	Z9C	0	0	1	0
12-123	F	1924		01	1945	17	1976	1	B3	0.0	Z9C	0	0	3	0
12-127	F	1917	1980	01	1941	17	1975	0	B6	0.0	Z9C	0	0	0	0
12-128	F	1920		01	1943	30	1978	2	C6	0.0	Z9C	1	0	7	0
12-129	F	1927		01	1946	4	1976	0	B6	0.0	Z9C	0	0	1	0
12-130	F	1924		01	1947	2	1976	5	B2	0.0	Z9C	1	0	12	0
12-133	F	1926		01	1946	7	1976	1	B3	0.0	Z9C	0	0	3	0
12-134	F	1927		01	1946	1	1975	0	B6	0.0	Z9C	0	0	0	0
12-135	F	1913		01	1943	6	1980	0	B6	0.0	Z9C	0	0	0	0
12-136	F	1928		07	1966	4	1975	1	B6	0.0	Z9C	0	0	1	0
12-141	F	1925		01	1943	3	1978	3	C3	0.0	Z9C	1	0	10	0
12-142	F	1922		01	1942	8	1976	0	B6	0.0	Z9C	0	0	0	0
12-143	F	1924		01	1942	56	1975	1	B6	0.0	Z9C	0	0	2	0
12-145	F	1921		01	1941	35	1976	0	B6	0.0	Z9C	0	0	0	0
12-146	F	1920		01	1943	32	1977	0	B6	0.0	Z9C	0	0	1	0
12-148	F	1925		01	1946	4	1975	0	B6	0.0	Z9C	0	0	0	0
12-150	F	1919		01	1943	104	1976	6	B3	0.0	Z9C	1	0	17	0
12-155	F	1929		01	1954	39	1976	0	B6	0.0	Z9C	0	0	1	0
12-163	F	1920		01	1942	78	1974	4	B3	0.0	Z9C	1	0	11	0
12-164	F	1920		01	1943	13	1976	0	B6	0.0	Z9C	0	0	1	0
12-165	F	1917		01	1947	78	1974	3	B3	0.0	Z9C	1	0	8	0
12-168	F	1926		01	1946	13	1975	1	B6	0.0	Z9C	0	0	3	0
12-171	F	1921		01	1940	4	1976	2	C6	0.0	Z9C	0	0	5	0
12-173	F	1930		01	1951	0	1974	2	B3	0.0	Z9C	0	0	4	0
12-174	F	1924		01	1948	18	1976	0	B6	0.0	Z9C	0	0	0	0
12-175	F	1927		01	1946	39	1975	1	B6	0.0	Z9C	0	0	1	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
12-178	F	1925		01	1943	8	1976	0	B6	0.0	Z9C	0	0	1	0
12-179	F	1924		01	1943	9	1976	1	B6	0.0	Z9C	0	0	2	0
12-182	F	1922		01	1942	26	1977	0	B6	0.0	Z9C	0	0	1	0
12-185	F	1920		01	1943	52	1975	0	B6	0.0	Z9C	0	0	0	0
12-186	F	1927		01	1945	4	1974	8	B2	0.0	Z9C	2	0	20	0
12-188	F	1936		07	1965	1	1976	1	B6	0.0	Z9C	0	0	0	0
12-190	F	1927		01	1947	3	1975	0	B6	0.0	Z9C	0	0	0	0
12-192	F	1921		01	1946	52	1976	1	B6	0.0	Z9C	0	0	2	0
12-193	F	1925		01	1942	1	1974	1	B6	0.0	Z9C	0	0	4	0
12-194	F	1924	1978	01	1946	5	1977	1	C6	0.0	Z9C	0	0	3	0
12-195	F	1925		01	1945	2	1976	1	B3	0.0	Z9C	0	0	3	0
12-197	F	1906		01	1922	13	1979	2	C6	0.0	Z9C	1	0	10	0
12-198	M	1909		07	1929	520	1981	0	C6	0.0	Z9C	0	0	0	0
12-199	M	1913		07	1934	104	1982	2	B6	0.0	Z9C	0	0	5	0
12-203	F	1913		16	1943	108	1980	0	G6	0.0	Z9	0	0	0	0
12-204	M	1918		06	1941	104	1977	0	C6	0.0	Z9C	0	0	0	0
12-206	F	1914		01	1942	130	1977	1	B6	0.0	Z9C	0	0	2	0
12-212	M	1930		17	1958	988	1977	2	C6	0.0	Z9C	0	0	1	0
12-214	F	1937		01	1967	26	1977	0	C6	0.0	Z9C	0	0	0	0
12-215	F	1936		01	1958	936	1977	0	B6	0.0	Z9C	0	0	0	0
12-216	F	1931	1979	01	1957	104	1977	0	B6	0.0	Z9C	0	0	0	0
12-218	M	1937		16	1955	17	1977	0	B6	0.0	Z9C	0	0	0	0
12-221	F	1914		07	1954	572	1977	1	B6	0.0	Z9C	0	0	1	0
12-223	F	1923		67	1963	728	1977	0	B6	0.0	Z9C	0	0	0	0
12-224	F	1927		01	1963	738	1977	0	B6	0.0	Z9C	0	0	0	0
12-225	F	1942		01	1962	17	1980	0	B6	0.0	Z9C	0	0	0	0
12-226	F	1926		17	1961	520	1977	0	B6	0.0	Z9C	0	0	0	0
12-228	F	1935		01	1959	22	1977	0	B6	0.0	Z9C	0	0	0	0
12-229	F	1921		01	1955	676	1977	1	B6	0.0	Z9C	0	0	1	0
12-231	F	1925		01	1958	104	1981	0	B6	0.0	Z9C	0	0	1	0
12-236	F	1928		01	1960	130	1977	1	B6	0.0	Z9C	0	0	1	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
12-237	F	1936		01	1954	52	1977	0	B6	0.0	Z9C	0	0	1	0
12-238	F	1936		01	1955	117	1981	1	B6	0.0	Z9C	0	0	1	0
12-239	F	1922		16	1956	104	1977	2	C6	0.0	Z9C	0	0	3	0
12-252	F	1920		01	1943	104	1979	1	B6	0.0	Z9C	0	0	2	0
12-258	F	1923	1981	01	1943	78	1978	2	C6	0.0	Z9C	0	0	5	0
12-259	F	1920		01	1943	104	1979	1	B6	0.0	Z9C	0	0	4	0
12-260	F	1915		01	1943	52	1979	3	B3	0.0	Z9C	1	0	10	0
12-262	F	1921		01	1942	52	1975	0	B6	0.0	Z9C	0	0	1	0
12-270	F	1919		01	1943	18	1975	0	B6	0.0	Z9C	0	0	1	0
12-271	F	1920		01	1943	77	1980	0	B6	0.0	Z9C	0	0	0	0
12-289	F	1921		17	1943	52	1978	0	C6	0.0	Z9C	0	0	0	0
12-294	F	1906		01	1936	360	1980	2	B3	0.0	Z9C	0	0	6	0
12-296	F	1895	1983	16	1941	104	1982	4	B2	0.0	Z9C	1	0	11	0
12-297	F	1923		01	1943	26	1978	0	C6	0.0	Z9C	0	0	1	0
12-299	F	1921		01	1943	104	1979	0	C6	0.0	Z9C	0	0	0	0
12-300	F	1915		01	1943	104	1980	0	B6	0.0	Z9C	0	0	0	0
12-302	F	1914		01	1943	1	1980	0	B6	0.0	Z9C	0	0	1	0
12-304	F	1923		01	1943	52	1975	0	B6	0.0	Z9C	0	0	0	0
12-308	F	1900		01	1942	52	1980	1	C6	0.0	Z9C	0	0	2	0
12-330	M	1928		07	1944	63	1974	1	B6	0.0	Z9B	0	0	2	0
12-331	M	1930		07	1944	65	1974	0	B6	0.0	Z9B	0	0	0	0
12-333	M	1932		06	1955	728	1974	3	B3	0.0	Z9C	0	0	2	0
12-334	F	1908		01	1924	17	1980	3	C3	0.0	Z9C	1	0	16	0
12-342	F	1915		01	1942	780	1979	7	G4	0.0	Z9	2	0	17	0
12-343	F	1900	1976	07	1918	208	1974	0	G6	0.00630	Z4	0	0	0	0
12-344	F	1908		07	1930	104	1974	0	B6	0.0	Z9B	0	0	0	0
12-346	F	1908		01	1926	3	1975	3	B3	0.0	Z9C	1	0	14	0
12-350	F	1906	1983	01	1923	39	1979	1	C6	0.0	Z9C	0	0	4	0
12-352	F	1906		06	1928	416	1975	1	B6	0.0	Z9C	0	0	5	0
12-358	F	1913		01	1940	520	1976	7	B2	0.0	Z9C	2	0	19	0
12-359	F	1914		16	1940	52	1979	1	B6	0.0	Z9C	0	0	4	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
12-364	F	1927		01	1968	364	1975	1	B6	0.0	Z9C	0	0	0	0
12-365	F	1931		01	1952	520	1975	1	B6	0.0	Z9	0	0	1	0
12-368	F	1923		01	1958	884	1975	2	C6	0.0	Z9C	0	0	1	0
12-370	F	1908		07	1924	104	1974	0	B6	0.01300	Z2B	0	0	0	0
12-375	F	1917		01	1958	312	1975	0	B6	0.0	Z9C	0	0	0	0
12-376	M	1945		07	1964	520	1977	0	B6	0.0	Z9C	0	0	0	0
12-377	F	1920		01	1961	676	1975	0	B6	0.0	Z9C	0	0	0	0
12-383	F	1909		01	1923	988	1977	0	G6	0.00159	Z5	0	0	0	0
12-384	F	1913		01	1929	75	1980	15	G4	0.0	Z9	5	0	66	0
12-385	F	1909	1981	01	1942	182	1979	8	C6	0.0	Z9C	2	0	24	0
12-390	F	1905		01	1929	7	1979	17	G4	0.0	Z9	5	0	75	0
12-392	F	1923		16	1942	52	1978	0	C6	0.0	Z9C	0	0	0	0
12-395	F	1921		01	1943	104	1982	1	B6	0.0	Z9C	0	0	2	0
12-397	M	1916		06	1947	520	1979	15	C3	0.0	Z9B	3	0	24	0
12-405	F	1942		01	1958	104	1982	1	C6	0.0	Z9C	0	0	1	0
12-421	M	1940		06	1968	260	1978	2	C6	0.0	Z9C	0	0	1	0
12-422	F	1907		01	1937	39	1975	0	B6	0.0	Z9B	0	0	0	0
12-425	M	1938		06	1960	6	1975	0	B6	0.0	Z9B	0	0	0	0
12-426	M	1923		07	1946	18	1975	1	B6	0.0	Z9B	0	0	2	0
12-428	F	1907		01	1922	13	1982	123	B1	0.0	Z9C	41	0	646	0
12-429	F	1922		01	1945	13	1975	0	B6	0.0	Z9C	0	0	0	0
12-430	F	1927		01	1941	26	1975	1	B6	0.0	Z9C	0	0	2	0
12-432	M	1937		06	1959	572	1977	1	B6	0.0	Z9C	0	0	0	0
12-436	F	1896	1979	01	1918	26	1975	1	B6	0.0	Z9C	0	0	4	0
12-437	F	1926		01	1943	104	1975	1	B6	0.0	Z9C	0	0	4	0
12-438	M	1942		06	1964	122	1977	1	C6	0.0	Z9C	0	0	1	0
12-442	M	1945		06	1971	56	1978	1	C6	0.0	Z9C	0	0	0	0
12-443	M	1919	1978	06	1945	13	1976	1	B6	0.0	Z9C	0	0	2	0
12-444	M	1950		06	1972	70	1980	2	B3	0.0	Z9C	0	0	1	0
12-447	M	1918		06	1940	260	1976	6	B2	0.0	Z9C	2	0	13	0
12-448	M	1923		67	1968	624	1979	1	B6	0.0	Z9C	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
12-450	M	1911		07	1946	20	1982	0	B6	0.0	Z9C	0	0	0	0
12-451	M	1949		06	1970	13	1977	0	C6	0.0	Z9C	0	0	0	0
12-452	M	1948		06	1970	52	1977	1	B3	0.0	Z9C	0	0	0	0
12-453	M	1914		06	1939	156	1979	9	B2	0.0	Z9C	2	0	20	0
12-455	M	1943		06	1970	87	1979	3	B3	0.0	Z9C	0	0	1	0
12-456	M	1918	1980	06	1938	364	1976	249	B1	0.0	Z9C	62	0	518	0
12-460	M	1923		17	1945	1092	1975	0	B6	0.0	Z9B	0	0	0	0
12-499	F	1908		01	1925	8	1980	0	C6	0.0	Z9C	0	0	1	0
12-502	F	1924		01	1945	13	1975	0	B6	0.0	Z9C	0	0	0	0
12-508	F	1937		17	1957	884	1975	0	B6	0.0	Z9C	0	0	0	0
12-509	F	1918		01	1941	160	1977	0	B6	0.0	Z9C	0	0	0	0
12-510	F	1923		01	1941	364	1977	1	C6	0.0	Z9C	0	0	3	0
12-515	F	1917		01	1941	52	1978	0	C6	0.0	Z9C	0	0	0	0
12-516	F	1918		01	1941	4	1979	3	B3	0.0	Z9C	1	0	9	0
12-518	M	1899		07	1941	104	1979	0	C6	0.0	Z9C	0	0	0	0
12-522	F	1921		01	1941	30	1977	0	B6	0.0	Z9C	0	0	1	0
12-523	F	1923		01	1941	104	1977	0	C6	0.0	Z9C	0	0	1	0
12-528	F	1917		01	1941	156	1979	1	B6	0.0	Z9C	0	0	3	0
12-529	F	1920		01	1941	104	1977	0	C6	0.0	Z9C	0	0	1	0
12-530	M	1920		07	1958	364	1976	3	B2	0.0	Z9C	1	0	3	0
12-532	M	1905		17	1929	2132	1980	1	C6	0.0	Z9C	0	0	2	0
12-533	F	1952		07	1970	260	1975	2	B6	0.0	Z9C	0	0	0	0
12-536	F	1929		16	1951	1664	1983*	2	B3	0.0	Z9C	0	0	1	0
12-544	F	1921		01	1941	534	1975	4	B3	0.0	Z9B	1	0	10	0
12-545	F	1920		01	1937	706	1982	12	B2	0.0	Z9C	3	0	38	0
12-547	F	1918		01	1942	1508	1975	3	B3	0.0	Z9B	0	0	4	0
12-548	F	1919		17	1939	832	1975	1	B6	0.0	Z9B	0	0	2	0
12-549	F	1917		01	1943	604	1975	2	B6	0.0	Z9B	0	0	5	0
12-552	F	1922		01	1940	338	1975	7	B3	0.0	Z9B	2	0	20	0
12-553	F	1922		01	1950	260	1976	0	B6	0.0	Z9C	0	0	0	0
12-556	F	1922		01	1942	213	1975	3	B3	0.0	Z9B	1	0	8	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
12-557	F	1919		01	1936	676	1976	2	B3	0.0	Z9C	1	0	7	0
12-559	F	1919		01	1939	104	1976	1	B6	0.0	Z9C	0	0	3	0
12-561	F	1917		16	1942	243	1975	0	B6	0.0	Z9B	0	0	0	0
12-563	F	1913		01	1940	289	1979	1	B6	0.0	Z9B	0	0	3	0
12-569	F	1922		01	1941	208	1978	0	C6	0.0	Z9C	0	0	0	0
12-570	F	1912		01	1941	29	1980	1	B6	0.0	Z9C	0	0	2	0
12-572	F	1914	1982	01	1941	78	1978	0	C6	0.0	Z9C	0	0	0	0
12-576	F	1921		17	1941	208	1978	1	C6	0.0	Z9C	0	0	3	0
12-579	F	1921		01	1941	208	1977	0	C6	0.0	Z9C	0	0	0	0
12-582	F	1914		01	1941	26	1977	0	C6	0.0	Z9C	0	0	0	0
12-583	M	1923		08	1923	39	1976	0	B6	0.0	Z9B	0	0	0	0
12-584	F	1907		07	1926	1820	1979	0	G6	0.0	Z9	0	0	0	0
12-620	F	1928		01	1966	169	1981	2	B3	0.0	Z9C	0	0	2	0
12-623	F	1934		01	1967	102	1977	0	C6	0.0	Z9C	0	0	0	0
12-624	F	1939		01	1965	312	1976	0	B6	0.0	Z9C	0	0	0	0
12-628	F	1945		01	1969	38	1981	0	B6	0.0	Z9C	0	0	0	0
12-635	F	1938		07	1967	156	1978	2	C6	0.0	Z9C	0	0	2	0
12-640	F	1946		07	1964	9	1977	0	B6	0.0	Z9C	0	0	0	0
12-643	F	1933		01	1957	126	1977	0	C6	0.0	Z9C	0	0	0	0
12-644	F	1934		01	1972	52	1977	1	B6	0.0	Z9C	0	0	0	0
12-645	F	1944		01	1963	156	1977	1	B6	0.0	Z9C	0	0	1	0
12-646	F	1946		01	1965	260	1977	0	B6	0.0	Z9C	0	0	0	0
12-650	F	1931		01	1949	1456	1977	2	B3	0.0	Z9C	0	0	1	0
12-652	F	1931		01	1953	56	1977	2	B3	0.0	Z9C	0	0	3	0
12-654	M	1942		07	1962	43	1977	3	B3	0.0	Z9C	0	0	3	0
12-656	M	1944		01	1962	104	1976	2	B2	0.0	Z9C	0	0	2	0
12-657	M	1924		06	1950	520	1977	6	B2	0.0	Z9C	1	0	8	0
12-660	M	1926		16	1955	39	1977	2	B3	0.0	Z9C	0	0	2	0
12-661	F	1946		01	1965	13	1977	0	B6	0.0	Z9C	0	0	0	0
12-665	F	1925		07	1971	260	1977	1	B6	0.0	Z9C	0	0	0	0
12-669	M	1957		07	1974	22	1977	0	B6	0.0	Z9C	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
12-670	M	1929		01	1951	52	1977	1	B3	0.0	Z9C	0	0	2	0
12-672	F	1920		01	1942	89	1979	2	B6	0.0	Z9C	1	0	6	0
12-675	F	1921		01	1952	30	1978	0	C6	0.0	Z9C	0	0	1	0
12-688	F	1917		01	1944	17	1977	1	B6	0.0	Z9C	0	0	2	0
12-693	F	1922		01	1942	0	1979	0	B6	0.0	Z9C	0	0	1	0
12-694	F	1931		01	1949	13	1976	0	B6	0.0	Z9B	0	0	0	0
12-695	F	1926		01	1951	133	1979	1	C6	0.0	Z9C	0	0	2	0
12-700	F	1929		01	1952	52	1978	2	C6	0.0	Z9C	0	0	4	0
12-702	F	1918		61	1942	160	1977	1	B6	0.0	Z9C	0	0	3	0
12-709	F	1925		01	1952	121	1976	0	B6	0.0	Z9C	0	0	0	0
12-710	F	1911		01	1952	104	1981	0	C6	0.0	Z9C	0	0	0	0
12-712	F	1906		01	1952	30	1981	0	B6	0.0	Z9C	0	0	0	0
12-729	F	1904		01	1944	6	1978	0	C6	0.0	Z9C	0	0	0	0
12-738	F	1922		01	1949	32	1979	0	C6	0.0	Z9C	0	0	0	0
12-739	F	1914		01	1954	17	1978	3	C6	0.0	Z9C	1	0	5	0
12-746	F	1913		01	1942	124	1976	0	B6	0.0	Z9B	0	0	0	0
12-748	F	1911		01	1944	13	1978	0	C6	0.0	Z9C	0	0	0	0
12-757	F	1922		01	1941	104	1976	1	B3	0.0	Z9C	0	0	4	0
12-764	F	1924		01	1952	104	1977	1	B3	0.0	Z9C	0	0	3	0
12-765	F	1921		71	1949	1352	1976	0	B6	0.0	Z9C	0	0	0	0
12-771	F	1930		01	1949	936	1976	0	B6	0.0	Z9C	0	0	0	0
12-773	F	1922		01	1944	17	1980	0	B6	0.0	Z9C	0	0	0	0
12-775	F	1916		01	1945	104	1981	0	B6	0.0	Z9C	0	0	0	0
12-777	F	1924		01	1942	2	1980	1	B6	0.0	Z9C	0	0	3	0
12-779	F	1929		01	1952	52	1976	0	B6	0.0	Z9C	0	0	0	0
12-782	F	1923		01	1945	8	1982	1	B6	0.0	Z9C	0	0	2	0
12-784	F	1930		01	1953	17	1977	1	C6	0.0	Z9C	0	0	1	0
12-788	F	1918		01	1951	160	1979	0	C6	0.0	Z9C	0	0	0	0
12-791	F	1920		01	1943	17	1979	2	B3	0.0	Z9C	0	0	5	0
12-795	F	1918		01	1949	17	1977	1	B6	0.0	Z9C	0	0	1	0
12-797	F	1922		01	1951	184	1979	2	C6	0.0	Z9C	0	0	3	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
12-802	F	1906		01	1943	14	1978	2	C6	0.0	Z9C	1	0	7	0
12-810	F	1910		01	1943	104	1977	0	B6	0.0	Z9C	0	0	0	0
12-815	F	1910		01	1943	8	1980	0	B6	0.0	Z9C	0	0	1	0
12-826	F	1906		01	1943	8	1977	2	C6	0.0	Z9C	1	0	6	0
12-829	F	1922		01	1949	18	1977	0	C6	0.0	Z9C	0	0	0	0
12-830	F	1917		01	1943	2	1981	1	B6	0.0	Z9C	0	0	4	0
12-831	F	1918	1979	01	1940	207	1978	1	B6	0.0	Z9B	0	0	3	0
12-841	F	1922		01	1952	1	1977	0	C6	0.0	Z9C	0	0	0	0
12-843	F	1916		01	1952	30	1979	0	B6	0.0	Z9C	0	0	0	0
12-849	F	1916		01	1941	208	1977	3	C6	0.0	Z9C	1	0	8	0
12-850	F	1917		01	1951	26	1977	0	B6	0.0	Z9C	0	0	0	0
12-857	F	1926		17	1951	208	1977	0	B6	0.0	Z9C	0	0	0	0
12-858	F	1917		01	1951	22	1978	0	C6	0.0	Z9C	0	0	0	0
12-863	F	1929		01	1953	11	1978	2	C6	0.0	Z9C	0	0	3	0
12-864	F	1919		01	1952	34	1978	0	C6	0.0	Z9C	0	0	0	0
12-872	F	1924		01	1943	8	1980	0	B6	0.0	Z9C	0	0	0	0
12-875	F	1921		01	1952	15	1979	0	B6	0.0	Z9C	0	0	0	0
12-878	F	1920		01	1949	237	1976	1	B6	0.0	Z9C	0	0	2	0
12-880	F	1917		01	1950	52	1977	1	B3	0.0	Z9C	0	0	3	0
12-884	F	1911		16	1944	27	1980	0	B6	0.0	Z9C	0	0	1	0
12-885	F	1918		01	1945	4	1978	2	C6	0.0	Z9C	1	0	6	0
12-887	F	1925		01	1942	78	1977	0	C6	0.0	Z9C	0	0	0	0
12-889	F	1924		01	1947	260	1976	1	B3	0.0	Z9C	0	0	2	0
12-891	F	1920		01	1952	8	1979	3	B3	0.0	Z9C	1	0	6	0
12-894	F	1914		01	1951	73	1980	0	B6	0.0	Z9C	0	0	0	0
12-901	F	1915		01	1951	13	1977	0	C6	0.0	Z9C	0	0	0	0
12-904	F	1922		01	1952	17	1980	2	B3	0.0	Z9C	0	0	4	0
12-905	F	1914		01	1949	312	1981	1	C6	0.0	Z9C	0	0	1	0
12-908	F	1923		01	1952	87	1976	0	B6	0.0	Z9B	0	0	0	0
12-916	F	1921		17	1942	676	1977	2	C6	0.0	Z9C	0	0	5	0
12-918	F	1918		01	1940	208	1977	1	B6	0.0	Z9C	0	0	3	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
12-924	F	1904		01	1950	17	1982	0	B6	0.0	Z9C	0	0	0	0
12-927	F	1919		01	1942	13	1977	2	B6	0.0	Z9C	0	0	5	0
12-929	F	1911		07	1942	4	1982	0	B6	0.0	Z9C	0	0	0	0
12-933	F	1923		01	1944	52	1979	2	B3	0.0	Z9C	0	0	5	0
12-941	F	1925		01	1944	2	1980	0	B6	0.0	Z9C	0	0	0	0
12-942	F	1898	1981	01	1944	+0	1977	2	C6	0.0	Z9C	0	0	5	0
12-943	F	1917		01	1952	52	1976	1	B6	0.0	Z9C	0	0	3	0
12-961	F	1913		01	1940	200	1980	6	B2	0.0	Z9C	2	0	20	0
12-963	F	1920		01	1942	104	1979	1	B3	0.0	Z9C	0	0	4	0
12-965	F	1924		01	1945	52	1977	2	B3	0.0	Z9C	0	0	5	0
12-967	F	1913		01	1953	12	1979	0	B6	0.0	Z9B	0	0	0	0
12-977	F	1920		01	1943	7	1978	1	C6	0.0	Z9C	0	0	2	0
12-978	F	1919		08	1919	39	1976	0	B6	0.0	Z9B	0	0	0	0
12-981	F	1907		01	1923	19	1977	0	B6	0.00907	Z2B	0	0	0	0
12-983	F	1921		01	1940	1040	1976	6	B2	0.0	Z9C	1	0	14	0
12-985	M	1934		08	1934	39	1976	1	B6	0.0	Z9B	0	0	3	0
12-986	M	1932	1976	08	1932	39	1976	2	B6	0.0	Z9B	1	0	5	0
12-987	F	1920		01	1940	65	1982	0	B6	0.0	Z9C	0	0	0	0
13-002	F	1901		61	1923	468	1977	0	B6	0.0	Z9C	0	0	0	0
13-007	M	1911		67	1951	676	1981	1	C6	0.0	Z9C	0	0	2	0
13-010	F	1923		01	1942	26	1977	2	B3	0.0	Z9C	0	0	5	0
13-011	F	1924		01	1942	39	1979	0	B6	0.0	Z9	0	0	0	0
13-015	F	1910	1979	01	1954	884	1976	1	B6	0.0	Z9C	0	0	1	0
13-019	F	1915		01	1942	104	1977	0	B6	0.0	Z9B	0	0	0	0
13-021	F	1914		01	1941	104	1979	0	B6	0.0	Z9B	0	0	0	0
13-022	F	1920		01	1942	69	1979	0	C6	0.0	Z9C	0	0	1	0
13-025	F	1914		01	1940	32	1977	0	C6	0.0	Z9C	0	0	0	0
13-026	F	1921		01	1941	26	1977	0	C6	0.0	Z9C	0	0	0	0
13-027	F	1922		01	1942	156	1977	1	C6	0.0	Z9C	0	0	[illegible]	0
13-030	F	1920		01	1940	416	1982	0	B6	0.0	Z9C	0	0	0	0
13-031	F	1923		01	1941	26	1982	1	B3	0.0	Z9C	0	0	5	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
13-037	F	1913		01	1941	52	1982	0	B6	0.0	Z9C	0	0	0	0
13-044	F	1954		07	1977	+0	1977	0	B6	0.0	Z9C	0	0	0	0
13-050	M	1932		07	1977	+0	1977	1	B6	0.0	Z9C	0	0	0	0
13-051	F	1878	1962	04	1925	+0	1949	700	G4	0.0	Z9	145	0	1648	0
13-055	F	1908		07	1923	11	1978	0	B6	0.00800	Z2	0	0	0	0
13-056	M	1958		06	1976	52	1977	3	C6	0.0	Z9C	0	0	0	0
13-057	F	1922		07	1976	104	1978	0	C6	0.0	Z9C	0	0	0	0
13-058	M	1956		16	1976	62	1977	0	C6	0.0	Z9C	0	0	0	0
13-059	M	1910		07	1933	2184	1978	1	B6	0.0	Z9B	0	0	1	0
13-063	F	1908		07	1933	1976	1978	0	B5	0.0	Z9B	0	0	0	0
13-064	F	1912		07	1959	102	1978	0	B6	0.0	Z9B	0	0	0	0
13-067	F	1917		01	1942	39	1978	0	B6	0.0	Z9B	0	0	0	0
13-071	F	1923		01	1942	78	1978	1	B6	0.0	Z9B	0	0	3	0
13-073	F	1924		01	1942	1352	1978	0	G6	0.0	Z9	0	0	0	0
13-078	F	1908		07	1942	1300	1978	0	B6	0.0	Z9B	0	0	0	0
13-080	F	1921		07	1939	312	1978	0	B6	0.0	Z9B	0	0	0	0
13-082	F	1920		01	1942	52	1978	2	B6	0.0	Z9B	1	0	6	0
13-085	F	1918		07	1942	936	1982	1	B6	0.0	Z9C	0	0	2	0
13-087	F	1925		01	1942	8	1978	0	B6	0.0	Z9B	0	0	0	0
13-088	F	1922		01	1942	8	1978	0	B6	0.0	Z9B	0	0	0	0
13-089	F	1923		01	1942	104	1978	0	B6	0.0	Z9B	0	0	0	0
13-092	F	1917		07	1952	1196	1979	0	B6	0.0	Z9B	0	0	0	0
13-102	F	1912		01	1928	936	1979	4	G6	0.0	Z9	1	0	14	0
13-107	F	1904		17	1936	1820	1978	5	B3	0.0	Z9B	1	0	9	0
13-108	F	1907		71	1926	2444	1978	2	B6	0.0	Z9B	0	0	4	0
13-109	F	1910		01	1943	1	1979	7	G6	0.0	Z9	2	0	21	0
13-113	F	1906		01	1926	2080	1978	2	B6	0.0	Z9B	0	0	5	0
13-115	F	1923		07	1959	52	1980	0	B6	0.0	Z9C	0	0	0	0
13-127	F	1914		07	1942	260	1978	1	B6	0.0	Z9B	0	0	3	0
13-132	F	1905		07	1932	1976	1978	3	B3	0.0	Z9B	1	0	6	0
13-136	F	1908	1982	07	1942	130	1978	0	B6	0.0	Z9B	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
13-138	F	1907		07	1942	520	1979	0	B6	0.0	Z9B	0	0	0	0
13-139	F	1922		01	1944	130	1978	4	B3	0.0	Z9B	1	0	11	0
13-145	F	1920		17	1937	468	1978	2	B6	0.0	Z9B	1	0	6	0
13-146	F	1921		01	1942	52	1978	1	B6	0.0	Z9B	0	0	3	0
13-147	F	1900		71	1922	1664	1979	1	B6	0.0	Z9B	0	0	5	0
13-148	F	1926		01	1946	52	1982	1	B6	0.0	Z9C	0	0	2	0
13-151	F	1904		07	1927	936	1978	1	B6	0.0	Z9B	0	0	4	0
13-152	M	1901		07	1941	208	1978	3	C6	0.0	Z9C	1	0	6	0
13-153	M	1908		07	1939	1352	1978	1	B6	0.0	Z9B	0	0	1	0
13-154	F	1905		07	1941	1248	1978	0	B6	0.0	Z9B	0	0	0	0
13-158	F	1920		01	1944	52	1979	1	B6	0.0	Z9B	0	0	3	0
13-160	F	1948		01	1966	52	1982	1	B6	0.0	Z9C	0	0	1	0
13-161	F	1948		01	1969	8	1978	2	C6	0.0	Z9C	0	0	1	0
13-165	F	1917		01	1943	104	1979	1	B3	0.0	Z9C	0	0	4	0
13-167	F	1928		07	1958	260	1979	0	B6	0.0	Z9B	0	0	0	0
13-169	M	1928		01	1953	988	1981	1	B6	0.0	Z9C	0	0	1	0
13-170	F	1923		01	1943	104	1979	0	B6	0.0	Z9C	0	0	0	0
13-175	F	1923		01	1944	52	1982	0	B6	0.0	Z9C	0	0	0	0
13-178	F	1935		01	1967	832	1983*	0	B6	0.0	Z9C	0	0	0	0
13-179	F	1937		01	1968	676	1983*	0	B6	0.0	Z9C	0	0	0	0
13-180	M	1910	1981	07	1978	98	1983*	3	A6	0.0	Z9	0	0	0	0
13-181	M	1925	1980	07	1977	109	1983*	3	A6	0.0	Z9	0	0	0	0
14-001	F	1933		17	1951	134	1982	0	B6	0.0	Z9C	0	0	0	0
14-002	F	1931		01	1951	22	1982	0	B6	0.0	Z9C	0	0	0	0
14-007	F	1930		07	1949	90	1983*	0	B6	0.0	Z9C	0	0	1	0
14-009	F	1933		01	1952	16	1983*	0	B6	0.0	Z9C	0	0	0	0
14-010	F	1929		01	1948	646	1983*	1	B6	0.0	Z9C	0	0	1	0
14-013	F	1928		01	1949	1144	1983*	3	B3	0.0	Z9C	1	0	4	0
14-014	M	1938		67	1959	550	1983*	0	B6	0.0	Z9C	0	0	0	0
14-022	F	1894	1980	01	1917	2184	1977	1	C6	0.0	Z9	0	0	7	0
14-023	F	1932		01	1951	96	1983*	0	B6	0.0	Z9C	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, µCi	(14) Input ^{228}Ra, µCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
14-026	F	1921		01	1950	1664	1983*	0	B6	0.0	Z9C	0	0	0	0
14-027	M	1917		07	1956	1196	1982	1	B6	0.0	Z9C	0	0	0	0
14-029	F	1933		01	1953	112	1983*	3	B3	0.0	Z9C	1	0	7	0
14-032	F	1936		07	1955	35	1983*	0	B6	0.0	Z9C	0	0	0	0
14-040	F	1930		01	1951	4	1983*	1	B6	0.0	Z9C	0	0	1	0
14-045	M	1937		07	1956	13	1983*	1	B3	0.0	Z9C	0	0	2	0
14-049	F	1932		07	1955	29	1983*	1	B6	0.0	Z9C	0	0	2	0
14-060	M	1932		76	1956	273	1983*	1	B6	0.0	Z9C	0	0	1	0
14-062	F	1941		07	1959	208	1983*	0	B6	0.0	Z9C	0	0	0	0
14-072	F	1935		01	1955	69	1983*	0	B6	0.0	Z9C	0	0	0	0
14-077	M	1932		07	1952	10	1983*	0	B6	0.0	Z9C	0	0	0	0
14-083	M	1938		07	1956	4	1983*	1	B6	0.0	Z9C	0	0	1	0
14-088	F	1936		07	1955	35	1983*	1	B6	0.0	Z9C	0	0	1	0
14-091	M	1935		07	1955	175	1983*	0	B6	0.0	Z9C	0	0	0	0
14-092	M	1937		07	1956	191	1983*	0	B6	0.0	Z9C	0	0	0	0
14-093	M	1932		07	1955	19	1983*	1	B6	0.0	Z9C	0	0	1	0
14-096	F	1935		07	1965	362	1983*	0	B6	0.0	Z9C	0	0	0	0
14-099	M	1917		07	1951	56	1983*	1	B6	0.0	Z9C	0	0	1	0
14-100	M	1937		67	1955	234	1983*	0	B6	0.0	Z9C	0	0	0	0
14-102	F	1932		07	1951	148	1983*	0	B6	0.0	Z9C	0	0	1	0
14-111	F	1935		17	1955	649	1983*	0	C6	0.0	Z9C	0	0	0	0
14-115	F	1937		17	1955	63	1983*	0	B6	0.0	Z9C	0	0	0	0
14-124	F	1934		01	1954	17	1983*	0	B6	0.0	Z9C	0	0	0	0
14-125	F	1931		01	1951	3	1983*	0	B6	0.0	Z9C	0	0	0	0
14-127	M	1934		07	1953	13	1983*	0	B6	0.0	Z9C	0	0	0	0
14-131	M	1945		07	1965	202	1983*	0	B6	0.0	Z9C	0	0	0	0
14-132	M	1934		06	1959	17	1983*	0	B6	0.0	Z9C	0	0	0	0
14-134	M	1918		71	1950	16	1983*	0	B6	0.0	Z9C	0	0	0	0
14-138	F	1936		17	1963	28	1983*	0	B6	0.0	Z9C	0	0	0	0
14-144	F	1915		17	1955	26	1983*	0	B6	0.0	Z9C	0	0	0	0
14-145	M	1932		61	1966	113	1983*	2	B3	0.0	Z9C	0	0	2	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
14-147	M	1927		76	1955	832	1983*	0	B6	0.0	Z9C	0	0	0	0
14-149	M	1920		07	1968	104	1983*	0	B6	0.0	Z9C	0	0	0	0
14-155	M	1910	1981	06	1942	520	1979	21	B2	0.0	Z9B	5	0	39	0
14-156	M	1945		01	1964	91	1983*	0	B6	0.0	Z9C	0	0	0	0
14-162	M	1914		67	1934	1872	1976	9	B2	0.0	Z9C	2	0	11	0
14-170	M	1925		76	1955	988	1982	1	B6	0.0	Z9C	0	0	1	0
14-180	F	1940		07	1961	156	1974	1	B6	0.0	Z9C	0	0	1	0
14-185	F	1930		01	1950	216	1983*	3	B6	0.0	Z9C	1	0	6	0
14-201	M	1923		07	1950	235	1983*	4	B2	0.0	Z9C	1	0	7	0
14-209	M	1933		16	1956	701	1983*	0	B6	0.0	Z9C	0	0	0	0
14-218	M	1929		07	1952	4	1983*	0	B6	0.0	Z9C	0	0	0	0
14-249	F	1938		17	1959	1040	1983*	0	B6	0.0	Z9C	0	0	0	0
14-252	M	1929		07	1953	15	1983*	0	B6	0.0	Z9C	0	0	0	0
14-261	M	1932		07	1956	602	1982	3	B6	0.0	Z9C	0	0	3	0
14-262	M	1912		07	1954	101	1983*	0	B6	0.0	Z9C	0	0	0	0
14-301	F	1932		01	1951	1664	1983*	0	B6	0.0	Z9C	0	0	0	0
14-327	M	1930		01	1955	30	1982	0	B6	0.0	Z9C	0	0	0	0
14-332	M	1921		06	1950	1508	1979	21	C3	0.0	Z9C	2	0	12	0
14-338	F	1928		01	1947	416	1976	5	B2	0.0	Z9C	1	0	10	0
14-340	F	1944		01	1966	92	1983*	1	B6	0.0	Z9C	0	0	1	0
14-341	M	1930		07	1954	2	1982	1	B6	0.0	Z9C	0	0	1	0
14-352	M	1926	1979	07	1948	1248	1973	0	B6	0.0	Z9C	0	0	0	0
14-377	F	1930		01	1948	52	1973	3	B3	0.0	Z9C	1	0	6	0
14-395	M	1921		07	1955	403	1983*	1	B6	0.0	Z9C	0	0	1	0
14-408	F	1928		01	1948	1352	1983*	1	B3	0.0	Z9C	0	0	2	0
14-410	M	1927		06	1951	1144	1973	8	B3	0.0	Z9C	1	0	4	0
14-422	M	1928		07	1952	468	1983*	0	B6	0.0	Z9C	0	0	0	0
14-440	F	1929		01	1952	84	1983*	0	B6	0.0	Z9C	0	0	0	0
14-442	M	1933		07	1955	91	1983*	1	B6	0.0	Z9C	0	0	1	0
14-445	M	1905		06	1928	2028	1982	215	B1	0.0	Z9C	51	0	400	0
14-450	M	1926		07	1955	817	1983*	4	B2	0.0	Z9C	1	0	4	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
14-467	F	1931		17	1955	1456	1983*	0	B3	0.0	Z9C	0	0	0	0
14-469	M	1914	1973	06	1945	138	1968	1	G6	0.0	Z9	0	0	1	0
14-512	F	1930		01	1948	6	1983*	0	B6	0.0	Z9C	0	0	0	0
14-513	F	1936		07	1955	20	1983*	0	B6	0.0	Z9C	0	0	0	0
14-514	M	1932		06	1955	780	1974	2	B3	0.0	Z9C	0	0	1	0
14-522	F	1924		16	1952	1144	1982	1	B6	0.0	Z9C	0	0	1	0
14-558	F	1936		17	1955	232	1983*	1	B6	0.0	Z9C	0	0	2	0
14-569	F	1922		01	1952	408	1983*	1	B6	0.0	Z9C	0	0	1	0
14-575	F	1944		07	1965	208	1982	0	C6	0.0	Z9C	0	0	0	0
14-582	M	1946		07	1965	156	1983*	3	B3	0.0	Z9C	0	0	2	0
14-590	F	1941		17	1965	780	1983*	0	B6	0.0	Z9C	0	0	0	0
14-620	M	1919		07	1950	884	1983*	2	B3	0.0	Z9C	0	0	2	0
14-623	F	1924		01	1948	1196	1974	0	B6	0.0	Z9C	0	0	0	0
14-627	M	1929		07	1953	101	1983*	0	B6	0.0	Z9C	0	0	0	0
14-636	F	1931		01	1951	39	1983*	0	B6	0.0	Z9C	0	0	1	0
14-650	F	1924		17	1950	1300	1983*	5	B2	0.0	Z9C	1	0	6	0
14-652	F	1928		01	1951	1248	1983*	0	B6	0.0	Z9C	0	0	0	0
14-661	F	1932		07	1950	312	1983*	1	B3	0.0	Z9C	0	0	3	0
14-675	M	1922		06	1953	156	1976	1	B3	0.0	Z9C	0	0	2	0
14-687	M	1919		06	1953	208	1972	0	B6	0.0	Z9C	0	0	0	0
14-726	M	1933		17	1966	76	1983*	0	B6	0.0	Z9C	0	0	0	0
14-728	F	1928		17	1948	1300	1983*	1	B6	0.0	Z9C	0	0	1	0
14-729	M	1930		07	1953	17	1983*	1	B6	0.0	Z9C	0	0	1	0
14-735	M	1891	1964	06	1915	1248	1959	82	B1	0.00700	Z7B	19	4	156	47
14-736	F	1935		01	1955	416	1983*	1	B3	0.0	Z9C	0	0	2	0
14-769	M	1922		17	1955	785	1983*	0	B6	0.0	Z9C	0	0	0	0
14-776	F	1931		01	1952	715	1983*	0	B6	0.0	Z9C	0	0	0	0
14-804	F	1925		16	1952	45	1983*	1	B6	0.0	Z9C	0	0	1	0
14-811	M	1917		06	1942	312	1968	30	G4	0.0	Z9	6	0	50	0
14-812	F	1932		01	1955	1092	1983*	0	B6	0.0	Z9C	0	0	0	0
14-833	M	1929	1983	07	1965	160	1982	0	B6	0.0	Z9C	0	0	0	0

TABLE A1. (cont'd.) Exposure Data for Radium Patients to End of 1983

(1) Case	(2) Sex	(3) Born	(4) Died	(5) Exp. Type	(6) Year First Exp.	(7) Exp. Dur. Wks.	(8) Year of Meas.	(9) ^{226}Ra, nCi	(10) ^{226}Ra, Method + Err.	(11) ^{228}Ra to ^{226}Ra, Ratio	(12) ^{228}Ra, Method + Err.	(13) Input ^{226}Ra, μCi	(14) Input ^{228}Ra, μCi	(15) Cum. Rads ^{226}Ra	(16) Cum. Rads ^{228}Ra
14-836	F	1929		01	1951	60	1983*	1	B6	0.0	Z9C	0	0	2	0
14-854	F	1928		01	1951	26	1983*	0	B6	0.0	Z9C	0	0	0	0
14-883	F	1927		06	1953	208	1978	0	C6	0.0	Z9C	0	0	0	0
14-887	M	1915		17	1955	821	1983*	0	B6	0.0	Z9C	0	0	0	0
14-891	M	1925		06	1948	1300	1973	10	B2	0.0	Z9C	1	0	6	0
14-908	F	1931		01	1952	24	1982	0	B6	0.0	Z9C	0	0	0	0
14-955	M	1926		07	1948	1456	1976	6	B2	0.0	Z9C	1	0	3	0
14-961	M	1929		07	1956	416	1982	0	B6	0.0	Z9C	0	0	0	0
15-046	M	1925		07	1959	780	1974	0	B6	0.0	Z9C	0	0	0	0
15-177	F	1938		71	1960	520	1983*	0	B6	0.0	Z9C	0	0	0	0
15-392	M	1933		07	1959	520	1983*	3	B2	0.0	Z9C	1	0	3	0
15-641	F	1920		07	1959	624	1983*	0	B6	0.0	Z9C	0	0	0	0
15-679	F	1939		71	1960	988	1983*	0	B6	0.0	Z9C	0	0	0	0

APPENDIX B. Radium-Induced Malignancies

Measured Persons

Tables B1 and B2 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 A1 of Appendix A.

There are 61 bone sarcoma cases and 32 sinus or mastoid carcinoma cases among the 2400 persons whose body contents 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 88 measured persons considered to have radium-induced malignancies.

There is one more case in Table B2 than appeared in the corresponding table in the 1983 annual report.[1] In 1983, a squamous-cell carcinoma of the left mastoid was diagnosed in Case 03-433,[2] whose skeletal dose at the time of diagnosis was 4280 rad.

Positive evidence is lacking that two of the cases (03-110 and 03-417) listed in Table B2 were bona fide cases of malignant tumor of the mastoid or paranasal sinuses. Case 03-110 had a possible carcinoma of the mastoid and a possible sarcoma of the left first metacarpal diagnosed radiographically in 1963; biopsy was refused. She died in 1967 of a myocardial infarction; autopsy was refused. Case 03-417 had an epidermoid carcinoma, which apparently arose in the right gingiva and invaded the right maxilla, diagnosed in 1962. She died with widespread metastases in 1966.

Unmeasured Persons

Tables B3 and B4 list exposed persons with unknown or uncertain radium content who had probable or confirmed bone sarcomas and probable or confirmed paranasal sinus or mastoid carcinomas, respectively. There are 24 probable or confirmed bone sarcoma cases and 5 probable or confirmed sinus or mastoid carcinoma cases among the approximately 1400 exposed persons with unknown or uncertain radium content for whom medical data are available. Six of the persons listed in Table B3 and two of the persons listed in Table B4 had early

TABLE B1. Bone sarcomas in persons with known radium body content as of 31 December 1983.

Case no.	Sex	Born	Exposed	Diagnosed	Died	Skel. Rads
00-003	F	1894	1917	1927	1927	44441
01-079	F	1901	1920	1942	1943	21115
01-032	F	1908	1924	1940	1940	18248
01-033	F	1908	1923	1930	1931	18023
03-584	F	1905	1923	1958	1959	16821
03-648[a]	F	1903	1922	1956	1956	16738
00-019	F	1895	1917	1946	1946	15042
01-009	F	1898	1918	1944	1945	14306
03-213	F	1892	1925	1954	1955	14049
00-027	F	1902	1918	1942	1942	13175
01-105	F	1898	1921	1945	1945	12555
00-006	F	1903	1918	1930	1930	11760
01-046	F	1903	1920	1942	1943	11190
00-004	F	1900	1917	1930	1931	11063
03-671	F	1906	1922	1952	1953	10975
05-215	F	1886	1917	1960	1968	10595
00-028	F	1902	1917	1930	1933	10265
01-172	F	1898	1916	1968	1968	9628
03-201	F	1909	1922	1962	1963	9586
01-389	F	1910	1923	1930	1930	9507
01-562	F	1901	1920	1931	1931	9393
01-103	F	1903	1922	1946	1946	7025
00-023	F	1900	1917	1929	1929	6928
03-215	M	1896	1925	1957	1971	6860
01-031	F	1906	1925	1934	1934	6824
03-401	F	1900	1923	1962	1963	6781
01-011	F	1872	1919	1936	1937	6678
00-005	F	1901	1917	1939	1939	6643
05-953	F	1902	1918	1977	1978	6589
03-619	F	1903	1922	1962	1962	6146
01-007	F	1886	1926	1948	1949	5972

Case no.	Sex	Born	Exposed	Diagnosed	Died	Skel. Rads
01-059	F	1905	1920	1962	1967	5182
03-118	F	1898	1931	1955	1955	5159
00-007	F	1903	1919	1934	1935	5046
03-429[a]	F	1908	1923	1967	1976	4387
01-051	F	1904	1923	1972	1977	4146
01-024	F	1901	1916	1956	1956	4085
03-234	F	1890	1915	1964	1965	3810
05-281	F	1898	1916	1956	1964	3804
03-402[a]	F	1905	1923	1953	1982	3727
01-179[a]	F	1890	1924	1943	1966	3642
01-239	F	1901	1917	1955	1958	3153
01-520	F	'382	1930	1967	1969	3132
01-073	F	1900	1921	1969	1969	3048
01-099	F	1905	1924	1942	1945	2923
01-026	F	1905	1925	1955	1958	2729
03-649	F	1906	1924	1953	1954	2670
01-025	F	1886	1924	1950	1952	2497
03-212	F	1902	1927	1951	1951	2412
03-210	M	1906	1926	1956	1958	2396
01-613	F	1906	1923	1935	1936	2319
01-268	F	1901	1917	1959	1968	1870
03-209	M	1894	1925	1958	1960	1698
03-216	F	1907	1922	1959	1961	1606
01-112	F	1908	1924	1954	1955	1547
03-455	F	1906	1922	1934	Living	1496
03-227	F	1878	1930	1949	1952	1470
03-110[a]	F	1899	1931	1963	1967	1467
03-106	F	1876	1931	1957	1959	1323
01-439	F	1880	1922	1949	1953	888
05-917	F	1902	1918	1981	1983	457[b]

[a]These cases also developed carcinomas of the paranasal sinuses or mastoid air cells. See Table B2.
[b]This estimate is probably low.

TABLE B2. Carcinomas of the paranasal sinuses and mastoid air cells in persons with known radium body content as of 31 December 1983.

Case no.	Sex	Born	Exposed	Diagnosed	Died	Skel. Rads
01-145	F	1900	1918	1957	1957	25701
01-008	F	1900	1917	1958	1958	22309
01-149	F	1888	1919	1958	1959	20067
01-087	F	1905	1921	1957	1979	18114
03-648[a]	F	1903	1922	1955	1956	16481
03-232	F	1898	1917	1956	1957	14736
01-006	F	1899	1919	1938	1938	8505
03-240	F	1916	1930	1953	1955	7655
03-206	M	1914	1936	1974	1975	7056
01-014	F	1901	1916	1949	1949	6799
03-676	F	1897	1924	1976	1977	6433
01-179[a]	F	1890	1924	1965	1966	6019
03-429[a]	F	1908	1923	1973	1976	4783
03-402[a]	F	1905	1923	1964	1982	4561
03-101	F	1908	1931	1970	1971	4448
01-171	M	1895	1914	1966	1975	4311
03-433	F	1904	1924	1983	Living	4276
03-407	F	1905	1923	1959	1961	4196
03-214	F	1895	1925	1959	1966	3964
03-235	F	1900	1928	1965	1968	3803
03-459	F	1906	1924	1980	1980	3537
03-126	F	1910	1931	1965	1965	3449
01-573	F	1892	1916	1945	1945	3307
03-105	M	1903	1931	1957	1957	3143
03-423	F	1907	1923	1971	1972	2036
03-417[b]	F	1909	1924	1962	1966	1894
03-141	M	1906	1933	1963	1963	1550
01-022	F	1900	1917	1951	1951	1544
03-110[a]	F	1899	1931	1963	1967	1467
05-284	F	1899	1919	1970	1973	1179
03-488	F	1907	1922	1973	1975	706
03-225	M	1922	1929	1981	Living	85[c]

[a]These cases also developed bone sarcomas. See Table B1.
[b]Carcinoma of case 03-417 apparently arose in R. gingiva (posterior maxilla).
[c]This is an uncertain estimate of skeletal absorbed dose. Case 03-225 ingested radium at 6 to 8 years of age. The absorbed dose was computed for a 7-kg adult-male skeleton from a radium-retention function determined in adults.

TABLE B3. Probable or confirmed bone sarcomas in exposed persons with unknown or uncertain radium body content.[a]

Case no.	Sex	Born	Exposed	Diagnosed	Died
00-011	F	1896	1917	1935	1936
00-013	F	1899	1917	1933	1933
00-030	F	1903	1918	1923	1924
00-031	F	1903	1920	1938	1940
00-035	F	1900	1917	1941	1941
01-088	F	1906	1923	1931	1931
01-107	F	1909	1923	1935	1935
01-108	F	1908	1924	1947	1947
01-117	F	1907	1922	1931	1931
01-387	F	1895	1918	1943	1943
01-465	M	1881	1925	1943	1943
01-695	F	1908	1923	1935	1935
03-658	F	1903	1922	1938	1938
03-660	F	1907	1923	1935	1936
03-661	F	1906	1922	1934	1934
03-665	F	1909	1924	1929	1930
03-680	F	1906	1924	1943	1946
03-759	F	1904	1924	1930	1930
03-800	F	1908	1924	1944	1945
03-806	F	1896	1922	1956	1956
03-848	F	1903	1922	1958	1958
05-534	F	1897	1917	1937	1939
05-987	F	1901	1918	1962	1962
09-087	M	1891	1912	1933	1934

[a]All persons were dial painters except cases 01-387 (therapeutic, i.v. and oral), 01-465 (drank Radithor), and 09-087 (chemist).

radioactivity measurements that were interpreted to show a positive indication of radium in the body. It had been anticipated that in the past year we would estimate the radium contents of several of these "unmeasured" persons on the basis of similar early measurements of other radium cases who were later measured by modern techniques. However, final estimates for these cases have been deferred pending the outcome of recently intensified efforts to exhume the unmeasured bone-sarcoma cases.[3]

TABLE B4. Probable or confirmed malignant tumors of the paranasal sinuses and mastoid air cells in exposed persons with unknown or uncertain radium body content.[a]

Case no.	Sex	Born	Exposed	Diagnosed	Died
01-587	F	1894	1919	1943	1943
03-675[b]	F	1896	1922	1959	1960
03-760	F	1907	1924	1946	1946
03-772	F	1904	1922	1953	1953
03-785	F	1903	1925	1953	1955

[a]All persons were dial painters.
[b]Death certificate lists paranasal sinus carcinoma as cause of death; histologic diagnosis from biopsy tissue was rhabdomyosarcoma of the maxillary antrum.

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PUBLICATIONS AND PRESENTATIONS BY THE STAFF OF
THE CENTER FOR HUMAN RADIOBIOLOGY
FOR THE PERIOD JULY 1983 THROUGH JUNE 1984

A. PUBLISHED PAPERS

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C. PAPERS SUBMITTED FOR PUBLICATION

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Irvin M. Citron and Richard B. Holtzman, Rare earth analysis in biological samples by atomic absorption using electrothermal atomization, Analytical Chemistry.

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J. H. Stebbings, Erythrocytic leukemia as a sex-determined response to chronic irradiation.

R. E. Toohey, J. Y. Sha, P. W. Urnezis and E. Y. Hwang, An unusual case of radium exposure.

THE CENTER FOR HUMAN RADIOBIOLOGY

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June 30, 1984

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