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RADIOLOGICAL AND ENVIRONMENTAL RESEARCH DIVISION ANNUAL REPORT

Center for Human Radiobiology

July 1980—June 1981

ARGONNE NATIONAL LABORATORY

ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

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RADIOLOGICAL AND ENVIRONMENTAL RESEARCH DIVISION ANNUAL REPORT

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July 1980-June 1981

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

March 1982

Preceding Report

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FOREWORD

This is the twelfth Annual Report of the Center for Human Radiobiology. The contents follow the pattern of previous reports in this series, i.e. a mixture of original countributions, abstracts of published papers, and summaries of papers presented at meetings. Paper 1 which is in the last category, describes a novel approach to the problem of risk analysis for radionuclides deposited in bone. Paper 2 continues the theoretical study of the induction of osteosarcoma by alpha-particle irradiation of cells lining bone surface, while paper 3 complements that work with a report on those cells. Paper 4 confirms for gamma rays the effect noted last year that cultured malignant cells of human origin are more resistant to radiation than are normal human fibroblasts. Papers 5 through 9 present different aspects of our studies of the metabolism and biological effects of radium. The last of these contains a large body of experimental data on the excretion of radium by persons who were exposed in different ways (inhalation, ingestion and injection). Papers 12 through 15 deal with plutonium; in the first of this group, the effects on the gastrointestinal adsorption of such factors as oxidation state, concentration, and adsorption onto teeth of plutonium in solution, have been clarified, leading to consistent results.

As usual, Appendix A contains relevant data on the exposure of the 2259 persons whose radium content has been determined at least once; this number represents an increase of 36 persons newly examined in calendar year 1980. While no more cases of osteosarcoma were reported, there was one new case of carcinoma of the sphenoid sinus, bringing the total of "head carcinomas" to 30, just half the number of cases of osteosarcoma in the 2259 "measured" subjects.

As an economy measure, the external distribution of this report has been reduced by about 35%. This was achieved by requiring those on last year's distribution list to request continued receipt of this and subsequent reports. However, it is not our intention to deprive anyone with a genuine interest in our work, from receiving the reports.

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Center for Human Radiobiology

RISK ESTIMATES FOR BONE*

R. A. Schlenker

Bone sarcoma data for $^{226,228}Ra$ and ^{224}Ra are analyzed within the dosage ranges where the observed risk is zero. The uncertainty in the risk may be effectively illustrated by using pairs of functions based on a statistically-based measure of confidence. For radiation protection, the appropriate measure of risk is cumulative incidence in the presence of competing risks, as this takes into account the reduction of radiation effects brought about by natural mortality.

Introduction

The primary sources of information on the skeletal effects of internal emitters in humans are the U.S. cases with occupational and medical exposures to $^{226,228}Ra$ and the German patients injected with ^{224}Ra primarily for treatment of ankylosing spondylitis and tuberculosis. During the past decade, dose-response data from both study populations have been used by committees, e.g., the BEIR committees, to estimate risks at low dose levels. NCRP Committee 57 and its task groups are now engaged in making risk estimates for internal emitters. This paper presents brief discussions of the radium data, the results of some new analyses and suggestions for expressing risk estimates in a form appropriate to radiation protection.

Dose Levels

Before risk can be discussed, the dose range of interest must be established. When the current NCRP recommendations for bone seekers[1] are translated into endosteal absorbed dose (10 μm tissue layer), one finds that exposure to an alpha emitter at the annual occupational limit for 50 years would deliver 10 to 1500 rad, depending on the radionuclide contained in the skeleton. Lower doses would presumably confer less risk, so the above dose range is taken to be the most important for radiation protection under non-accidental exposure conditions.

*Based on a talk given at the Seventeenth Annual Meeting of the NCRP, April 8-9, 1981, Washington, D.C.

Risk Definitions

A second concern is the definition of risk. Tumor rate and cumulative incidence are used here. Specifically, tumor rate, $\dot{P}(t)$, is the probability per unit time that a person with a given dosage will contract cancer; cumulative incidence is the ratio of the number of persons who contract cancer during their lifetimes to the number exposed at a given dosage. Cumulative incidence in the absence of competing risks will be denoted by ν/N, and cumulative incidence in the presence of competing risks will be denoted by n/N.

$^{226,228}Ra$

Figure 1 shows a dose-response plot for bone sarcomas following combined exposure to $^{226,228}Ra$.* Risk, called "bone sarcomas/person-year" on the graph, is nearly the same as time average tumor rate, $\dot{P}$. Dosage is expressed as the initial intake to blood, in μCi, of ^{226}Ra plus 2.5 times the intake, in μCi, of ^{228}Ra. A fifty-year endosteal dose of 1500 rad corresponds to about 200 μCi on this scale of intake. Most of the intake groups below this level show zero observed risk. They will be considered separately because they contain the risk information for low doses.

Using the binomial distribution, one can determine the probability that the true risk exceeds a given value when the observed risk is zero; in Figure 2, there is a 5% chance in each intake group that the actual risk exceeds the level shown by the stair-step line. The chance that the true risk exceeds the 5% level in all seven intake groups at once is $(0.05)^7 \cong 8 \times 10^{-10}$; thus, there is only a minute probability that the actual dose-response curve lies above the stair-step line. This sort of analysis emphasizes the uncertainty in the data and provides one way of judging the adequacy of proposed dose-response relationships. It could be repeated for any percentage chance; e.g., the 50% levels would be one-quarter of the 5% levels and the probability that the true dose-response curve exceeds the 50% level in all seven intake groups at once would be 7.8×10^{-3}.

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*The graph with its dose-response curve was copied from Rowland, Stehney and Lucas.[2] All other dose-response curves and data analyses are the author's work. All dose-response functions are listed in Tables 1 and 2.

Table 1. Single Dose-Response Functions

Fig. No.	Label	Function[a]
1	--	$\dot{\bar{P}} = (10^{-5} + 6.8 \times 10^{-8}Q^2)e^{-1.1 \times 10^{-3}Q}$
2	5%	$\dot{\bar{P}} = 10^{-5} + 1.2 \times 10^{-5}Q - 1.5 \times 10^{-8}Q^2$
	50%	$\dot{\bar{P}} = 10^{-5} + 1.3 \times 10^{-7}Q + 5.6 \times 10^{-8}Q^2$
	RSL(48%)	Same as Fig. 1
4	--	$\nu/N = 1 - e^{-3.0 \times 10^{-5}D}$
5	5%	$\nu/N = 3 \times 10^{-5} + 8.0 \times 10^{-5}D - 7.3 \times 10^{-8}D^2$
	50%	$\nu/N = 3 \times 10^{-5} - 2.1 \times 10^{-7}D + 4.0 \times 10^{-8}D^2$
	20%	Same as Fig. 4

[a] Q is μCi intake to blood of ^{226}Ra plus 2.5 times the μCi intake to blood of ^{228}Ra. D is endosteal absorbed dose in rad. The functions for Figures 1 and 4 are valid above 0.5 μCi and 25 rad, respectively; functions for Figure 2 are valid between 0.5 and 100 μCi; functions for Figure 5 are valid between 25 and 500 rad.

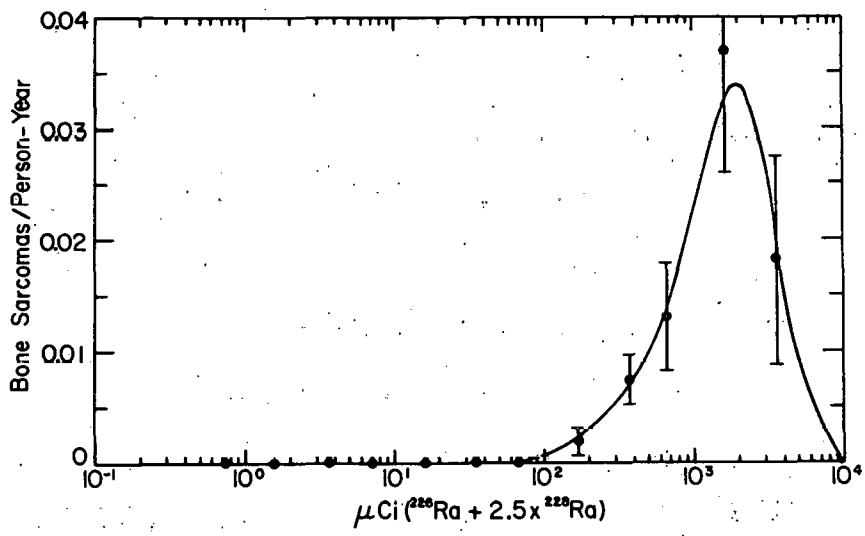

FIG. 1.--Dose response for bone sarcomas in humans following intake of $^{226,228}Ra$.

Table 2. Dose-Response Envelopes

Fig. No.	Label	Functions[a]
3	RSL, 9%	$\bar{\dot{P}} = (10^{-5} + 8.0 \times 10^{-8}Q^2)e^{-1.1 \times 10^{-3}Q}$
		$\bar{\dot{P}} = (10^{-5} + 5.6 \times 10^{-8}Q^2)e^{-1.1 \times 10^{-3}Q}$
	68%	$\bar{\dot{P}} = (10^{-5} + 6.1 \times 10^{-6}Q + 2.1 \times 10^{-8}Q^2$
		$Q < 26.8$ μCi: $\bar{\dot{P}} = 10^{-5}$
		$Q \geq 26.8$ μCi: $\bar{\dot{P}} = 10^{-5} + 7.9 \times 10^{-8}(Q-26.8)^2$
	95%	$\bar{\dot{P}} = 10^{-5} + 1.6 \times 10^{-5}Q - 3.6 \times 10^{-8}Q^2$
		$Q < 57.5$ μCi: $\bar{\dot{P}} = 10^{-5}$
		$Q \geq 57.5$ μCi: $\bar{\dot{P}} = 10^{-5} + 1.3 \times 10^{-7}(Q-57.5)^2$
6	14%	$\nu/N = 1 - e^{3.6 \times 10^{-5}D}$
		$\nu/N = 1 - e^{-2.3 \times 10^{-5}D}$
	68%	$\nu/N = 3 \times 10^{-5} + 3.8 \times 10^{-5}D - 1.2 \times 10^{-8}D^2$
		$D < 226$ rad: $\nu/N = 3 \times 10^{-5}$
		$D \geq 226$ rad: $\nu/N = 3 \times 10^{-5} + 8.1 \times 10^{-8}(D-226)^2$
	95%	$D < 235$ rad: $\nu/N = 3 \times 10^{-5} + 1.8 \times 10^{-4}D - 4.0 \times 10^{-7}D^2$
		$D \geq 235$ rad: $\nu/N = 0.0218$
		$D < 314$ rad: $\nu/N = 3 \times 10^{-5}$
		$D \geq 314$ rad: $\nu/N = 3 \times 10^{-5} + 1.2 \times 10^{-7}(D-314)^2$

[a] Except for Figure 6, 95%, the first line of each entry gives the upper function and subsequent lines give the lower funtion. For Figure 6, 95%, the first two lines give the upper function. Q is intake, D is endosteal dose, functions of Q are valid between 0.5 and 100 μCi, functions of D apply to the range 25 to 500 rad.

Other analyses of the zero-risk data are possible. The curve marked 5% in Figure 2 is a quadratic which equals the naturally occurring risk at zero intake and fits the observed risk at the first intake level where the risk is non-zero; there is a 5% chance that the true number of tumors for the entire zero-risk region exceeds the number predicted by the curve. Similarly, 48% and 50% mean a 48% or 50% chance for the true number of tumors to exceed the predicted number. The dose-response curve of Figure 1, labeled RSL(48%) in Figure 2, and the 50% curve are almost indistinguishable. Although quadratics were chosen for the 5% and 50% curves, any shape would have been acceptable if it had no regions where risk decreased as intake increased.

If risk is represented by a single dose-response function, the one marked 50% in Figure 2 is probably the best choice since it equalizes the chances of overpredicting and underpredicting the correct total number of tumors. However, a pair of dose-response functions based on a confidence interval offers an attractive alternative to a single function. Three pairs (confidence evelopes) are shown in Figure 3. For the 95% pair, there is a 2.5% chance that the true number of tumors in the zero-risk region exceeds the number predicted by the upper curve and a 2.5% chance that the true number is less than predicted by the lower curve; therefore, the chance is 95% that the true number lies between the two predictions. Sixty-eight percent and 9% have analogous meanings.

The upper curves in the 68% and 95% envelopes are quadratics and the lower curves are piecewise continuous functions composed of horizontal segments whose value is the natural tumor rate, and quadratic segments which fit the observed risk at the first intake level where that is non-zero.

The boundaries of the shaded envelope correspond to two standard deviations on either side of the Rowland, Stehney and Lucas dose-response function and were calculated from the standard errors of the parameters. If the parameters were normally distributed, there would be a 95% chance for the true dose-response function to lie within the shaded area. This high probability conflicts with the small chance (9%) for the expected number of tumors to lie between the predictions of the boundary curves. One reason for the discrepancy is the method used to determine the parameters' errors. They are calculated from the residuals in a non-linear least square fitting procedure. Examination of Figure 1 shows that the best fit curve passes much closer to the data points than one would expect on the basis of the error

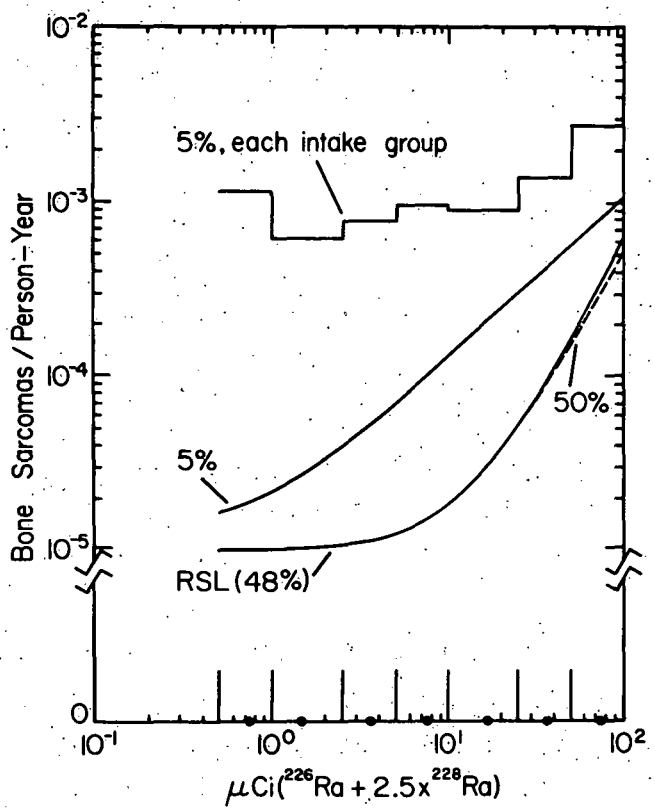

FIG. 2.--Dose-response curves for $^{226,228}Ra$ in region of zero observed risk.

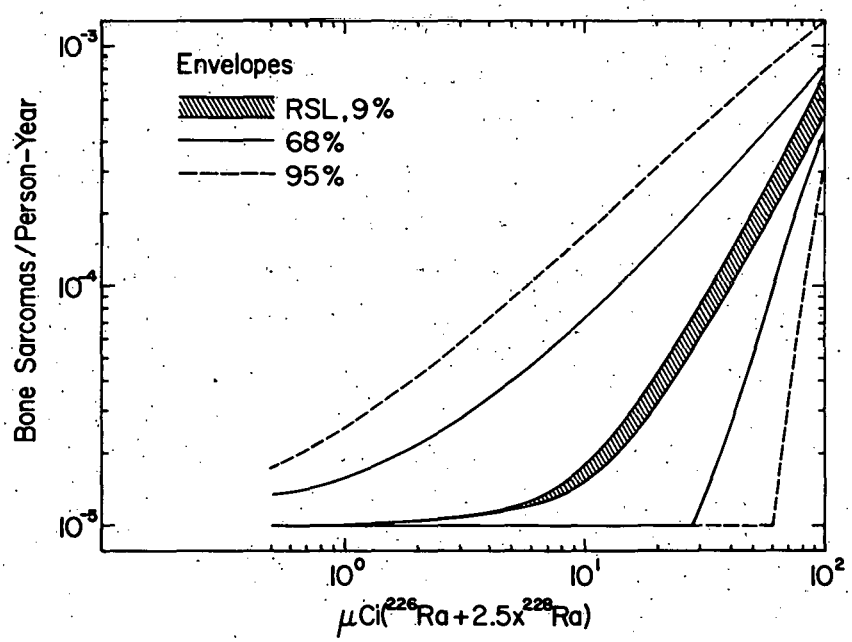

FIG. 3.--Dose-response envelopes for $^{226,228}Ra$.

bars. This makes the residuals and the standard errors in the parameters unrealistically small. The 68% and 95% curves provide a more realistic reflection of the uncertainty in the data than does the shaded envelope.

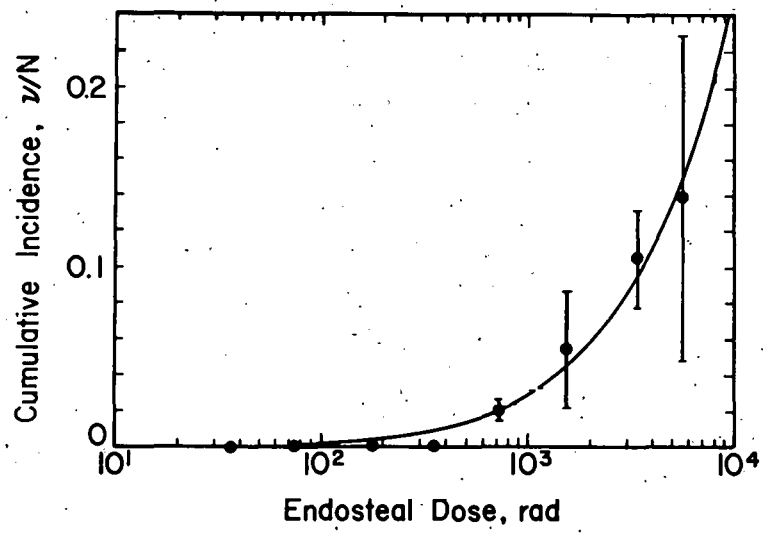

FIG. 4.--Dose-response plot for bone sarcomas in humans injected with ^{224}Ra at age 16 or older.

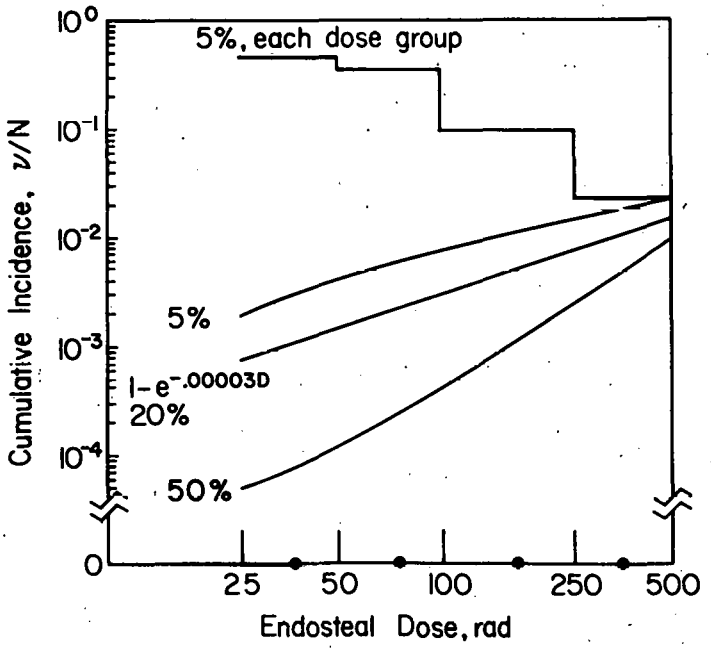

FIG. 5.--Dose-response curves for ^{224}Ra in region of zero observed risk.

^{224}Ra

Analyses of ^{224}Ra data were patterned after those for $^{226,228}Ra$. Figure 4 is a dose-response plot for persons 16 years or older at injection. Risk is expressed as cumulative incidence in the absence of competing risks, i.e., ν/N. The data points and error bars were obtained by a life table analysis (unpublished) of Spiess' and Mays' data.[3,4] The curve was determined by a non-linear least square fitting procedure similar to that used by Rowland, Stehney and Lucas. Figure 5 shows 5% and 50% stair-step lines similar to those in Figure 2. The curve labeled 20% is the dose-response function from Figure 4; its mathematical form is written beside it. The steady rise in the stair-step line with diminishing dose is due to a steady drop in the number of subjects in each dose group. Figure 6 shows 3 pairs of curves similar to those in Figure 3. At their widest, the 95% curves span a factor of 750 compared with a factor of 90 for the 95% curves in Figure 3. This reflects the fact that much less low dose information is available for ^{224}Ra than for $^{226,228}Ra$, owing principally to a smaller number of cases and shorter follow-up periods for ^{224}Ra. The shaded envelope is again unrealistically narrow because the data points in Figure 4 pass the curve unusually closely.

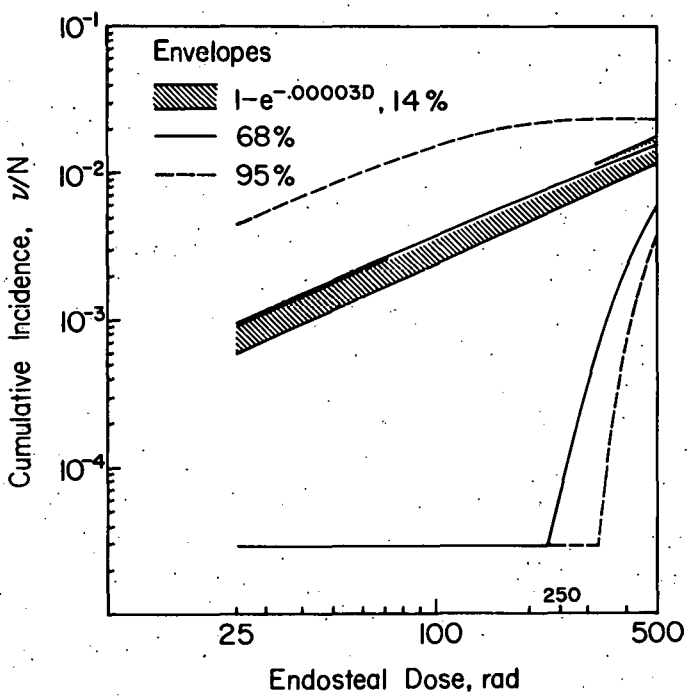

FIG. 6.--Dose-response envelopes for ^{224}Ra. The upper curve of the 68% envelope is nearly coincident with the upper boundary of the shaded envelope.

Risk and Radiation Protection

Although it is seldom stated, radiation protection is affected by natural mortality, as well as mortality from radiation effects. The reason is simple: if a person dies before a radiation effect becomes life threatening, then radiation exposure has not reduced his life span; thus, the actual impact of radiation exposure is lessened by natural mortality. When stating cancer risk for radiation protection purposes, this effect should be taken into account. Neither tumor rate nor ν/N, the cumulative incidence in the absence of competing risks, is capable of doing so; n/N, the cumulative incidence in the presence of competing risks, does account for death from natural causes and is the appropriate measure of risk for radiation protection. Not surprisingly, n/N is dependent on the age at exposure, because death rates and the expected survival vary with age.

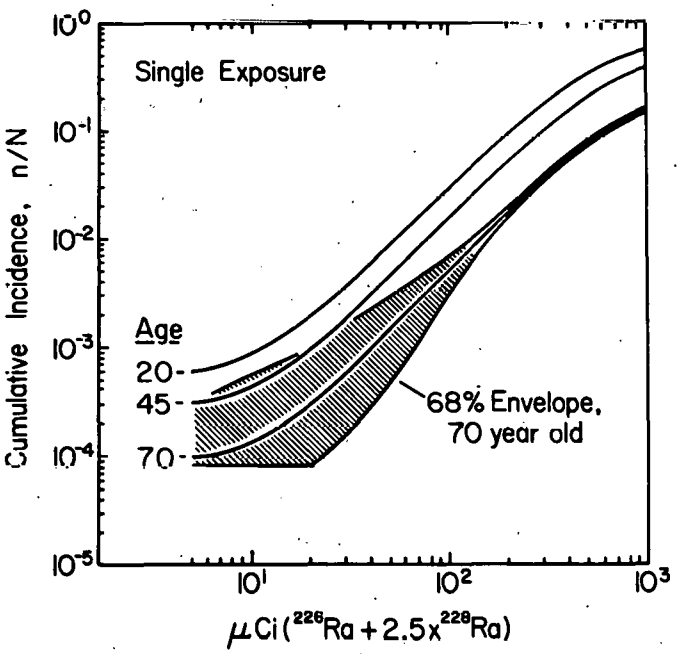

FIG. 7.--Cumulative incidence in presence of competing risks following single intake of $^{226,228}Ra$.

Figure 7 provides an example of the presentation of risk informtion for use in radiation protection. Single intake at 20, 45 or 70 years of age is assumed. The cumulative incidence has been calculated from the time average tumor rate for $^{226,228}Ra$ using the following equation:

$$\frac{n}{N} = \int_A^{100} da\ \bar{\dot{P}}\ e^{-\int_A^a [\bar{\dot{P}} + \dot{S}(a)]da} \quad , \tag{1}$$

where a is the age in years, A is the age at exposure, and $\bar{\dot{P}}$ is the time average tumor rate, equal to zero until a 5-year latent period has passed, and constant thereafter; $\dot{S}(a)$ is the death rate from all other causes, including radium-induced carcinomas of the mastoids and paranasal sinuses, for which the latent period is 10 years. Eq. 1 is a simplification of the more general equation,

$$\frac{n}{N} = \int_0^{\infty} da\ \bar{\dot{P}}(a)\ e^{-\int_0^a [\bar{\dot{P}}(\tau) + \dot{S}(\tau)]d\tau} \quad , \tag{2}$$

which must be used when tumor rate $\dot{P}(a)$ varies with time.

For the curves labeled 20, 45 and 70,

$$\bar{\dot{P}} = (10^{-5} + 6.8 \times 10^{-8} Q^2) e^{-1.1 \times 10^{-3} Q} \quad , \tag{3}$$

where Q is the intake. The boundaries of the 68% envelope were calculated using the 68% functions of Figure 3. The Rowland, Stehney and Lucas linear dose-response function for mastoid and sinus carcinomas[1] was used to determine rates for these tumors. The death rate from natural causes was obtained by fitting a continuous function to Monson's data for women.[5] Exclusion of male death rates has only a minor effect on the result but is perhaps appropriate because only female subjects were considered by Rowland, Stehney and Lucas.

Space limitations forbid the inclusion of envelopes for all three ages of intake. The missing envelopes are similar to the one shown. The envelope width is most reflective of the true uncertainty below 100 μCi intake. At higher intakes, the envelope is narrowed excessively by the requirement that the bounding functions fit the observed risk in the lowest intake group where that is non-zero. This is of little consequence because intakes less than 100 μCi correspond to the endosteal dose range of most interest. The risk values in Figure 7 were obtained by numerical integration. No simple equations for the curves are available.

Summary

The doses of interest in radiation protection lie mainly within dosage ranges for $^{226,228}Ra$ and ^{224}Ra where the observed risk is zero. Knowledge of

the shapes of the dose-response functions in these ranges is especially poor, and many functions which do not decrease with increasing dosage are consistent with the data. Second-degree polynomials were used in this paper, where feasible, because of their simplicity.

Although single functions can be used, the low dosage data are better represented by pairs of functions (dose-response envelopes) which define the upper and lower boundaries of a domain with which a statistically related measure of confidence can be associated. The measure used here was percentage chance that the correct total number of tumors in the zero-risk region lay between the numbers predicted by the pairs of functions. This probability value is firmly based on binomial statistics and can be easily derived for any pair of functions.

Several measures of risk are currently in use. Each is appropriate for different purposes. The one which should be used in radiation protection is cumulative incidence in the presence of competing risks since this takes into account the reduction of radiation effects brought about by natural mortality.

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TRACK STRUCTURE FOR ALPHA PARTICLES IN WATER

A. Pagnamenta* and J. H. Marshall

We have refined our earlier construction of the alpha-particle ionization tree by producing better fits to the available data. We use parametric representations of the different ionization processes and use the observed energy dependence of the charge equilibria. This permits us to compute the number of primary ionizations per micron per keV secondary energy and the total number of ions on the basis of the ionization cross section and the experimentally established energy loss alone.

Introduction

In our search for a direct mechanism for the disruption of the information within DNA which may be related to cancer initiation, we have been developing analytical descriptions of the track structures of alpha particles and beta particles in water. In particular, we want to know the number of ionizations per micron of particle track which occur on the main track and on all the subsidiary electron tracks.

For our application, we need quantitatively accurate expressions beginning with the highest available alpha-particle energies (MeV) all the way down to the very low energies (tens to hundreds of keV), the region in which the resulting ionization density is largest. The alpha-particle range at these low energies is still many times the transverse dimension of the DNA molecule. The speed of the alpha particle has become comparable to the speed of the atomic electrons, which makes computation from first principles impractical. We have therefore developed empirical parametric expressions for the different components of the ionization cross section which describe the data accurately and extend the theoretically and experimentally established results of the MeV region down into the high keV region. From our description, we hope to be able to compute the probability, as a function of the incident particle energy, for placing a small number of ionizations within distances comparable to the diameter of DNA.

In our last report,[1] we had completed both tree-like structures in a

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preliminary way, but the one for the alpha particle was based merely on the Rutherford formula for the collision of an alpha particle with a free electron at rest. It included the contributions from the bound electrons only in a qualitative way and ignored three-body effects (convoy electrons and stripping). We had accounted for the changing charge states of the slowing-down alpha particle by the introduction of an energy-dependent effective charge. All these effects become important in the interesting high keV region of the alpha particle and must be considered more accurately.

In this report, we present the results of a number of refinements of this calculation which have permitted us to extend our results reliably to energies considerably below T = 1 MeV (250 keV/amu). At energies much lower than 1 MeV, the speed of the alpha particle is comparable to the speed of the atomic electrons. Quantum mechanical calculations which are usually carried out in first Born approximation become useless. This is best demonstrated by the failure of the otherwise accurate Bethe-Bloch[2,3] expression for the LET below 1 MeV. Theoretical refinements would have to be of quantitative accuracy and therefore would have to include accurate bound state wave-functions (which are not available), second order Born calculations (which have proved cumbersome) and three-body effects in the form of Faddeev equations (which have been solved in the first Born approximation only[4]). We have been able to extend the theoretically supported results of the MeV region in an empirical way to the lower energies on the basis of the new data by Toburen, Wilson and Popowich[5] on the emission of secondary electrons in water vapor for both He^{++} and He^{+}, at energies of 0.8, 1.2, 1.6, and 2.0 MeV. We have used these data to construct analytical expressions for the differential cross sections for secondary electron production in water vapor by He^{++}, He^{+}, and He^{o}, the different charge states of the alpha particle as it slows down. This includes the construction of cross sections for hard collisions, glancing collisions, for the convoy effect, and for Auger and stripping electrons. The energy-dependent probabilities for finding the alpha particle in the different charge states have been taken from the measurements by Armstrong.[6]

At the high energy end of the secondary electron spectrum, we had to modify our expressions (which are based on collisions with electrons at rest) by the empirical introduction of an effect due to the motion of the electrons within the water molecule (smearing). The result is an effective ionization cross section and expressions for the number and energies of electrons

produced per micron of alpha-particle track. To obtain the number of secondary electrons originating in turn from each delta ray, we are making use of our earlier beta-ray calculation, which we have available in analytical form. The resulting integrals need special methods for their evaluation, which we have at present under investigation. We account for the energy loss of the alpha particle by the use of the measured LET values we have collected and parametrized in a convenient form.

After evaluation of the integrals mentioned, we will be able to evaluate the total number of ionizations along the alpha-particle track. At the higher energies, our preliminary results show that our method produces values for W, the energy per ion pair, which are in good agreement with the experimental data for tissue-equivalent gas.[7] At the very lowest energies, below T = 300 keV, there are no data available, either on the ionization cross sections or on the LET for the alpha particle. Here we have extrapolated our expressions by the use of a differential relation between LET, W, and the number of ionizations per micrometer in a way consistent with the newest values for W.[8] This was possible because at these low energies the secondary electrons do not contribute much to the total number of ionizations.

The Ionization Cross Section for He^{++}

We are first interested in the differential cross section $d\sigma/dQ$ for the alpha particle or He^{++}. This cross section gets contributions from the following processes:

Hard Collisions: the binding energy can be neglected.

Soft Collisions: bound electrons.

Convoy electrons: the electron is dragged out of the atom at near alpha-particle speed under long time action of the alpha potential (continuum charge transfer).

Auger Electrons: the release of an outer shell electron by the filling of a K-shell vacancy.

We write the differential cross section as

$$\frac{d\sigma}{dQ}(T,Q) = \frac{d\sigma}{dQ}\Big|_{Ruth} \left[Z(T) + Y_{Soft}(T,Q) + Y_{Convoy}(T,Q) + Y_{Auger}(T,Q)\right], \qquad (1)$$

where T is the kinetic energy of the incident alpha particle and Q is that of

the secondary electron, and

$$\left.\frac{d\sigma}{dQ}\right|_{Ruth}(T,Q) = \frac{16\pi\, a_o^2\, R^2}{\frac{m_e}{m_\alpha}\, T(Q + B)^2} \qquad (2)$$

is the Rutherford cross section for the collision of an alpha particle (of charge 2) with a single free electron at rest. For ease of computation, e^4, where e is the electron charge, has been replaced by $4\, a_o^2\, R^2$, where a_o = 0.529 Å is the Bohr radius of the hydrogen atom and R = 13.6 eV is the Rydberg constant. The kinetic energy of the nonrelativistic alpha particle is $T = \frac{1}{2} m_\alpha v_\alpha^2$, where m_α and v_α are the mass and speed of the alpha particle, and m_e is the mass of the struck electron. The term B has been added to the denominator of the free particle Rutherford formula to account for the influence of the binding, which keeps the number of scattered electrons finite as Q approaches zero. As the dominant contribution comes from the outer shell electrons, we take B = 12.6 eV, the first ionization potential of the water molecule.

The function Z(T) indicates the number of electrons per water molecule which, at a given alpha particle energy, T, are described by the hard (Rutherford) collision term (Eq. 2). At energies much below 1 MeV the alpha particle is moving so slowly that the Born approximation no longer applies. We have therefore cut off this rapidly decreasing term at T = 0.1 MeV. The exact cutoff point is not significant as long as the cutoff is smooth.

A fit to the data* indicates that, from 0.8 to 2.0 MeV, 3 to 5 electrons per water molecule contribute to the hard collisions (Figure 1). At infinite energy one would expect all 10 electrons to contribute. However, it turns out that the K-shell electrons contribute so much less than the others[9] that not much more than 8 electrons can be considered "free" in our energy range. The function

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*The evaluation of the energy loss to main-track ionization alone (see below) which has to be less than the entire energy loss and the computation of the energy per ion pair, has motivated us to multiply the data of Toburen et al.[5] by an overall factor of 0.85. This reduction of the overall cross section by 15% is well within the stated accuracy of the absolute normalization of this experiment.

$$Z(T) = \frac{8.5(T - 0.1)^2}{T(T + b_z)} \quad (T > 0.1 \text{ MeV}) \tag{3}$$

$$Z(T) = 0 \quad (T < 0.1 \text{ MeV}) \quad , \tag{4}$$

with b_z = 1.1 MeV, fits the four points derived from our fits to the data. It has the proper slope in the region of data and extrapolates reasonably to both lower and higher energies.

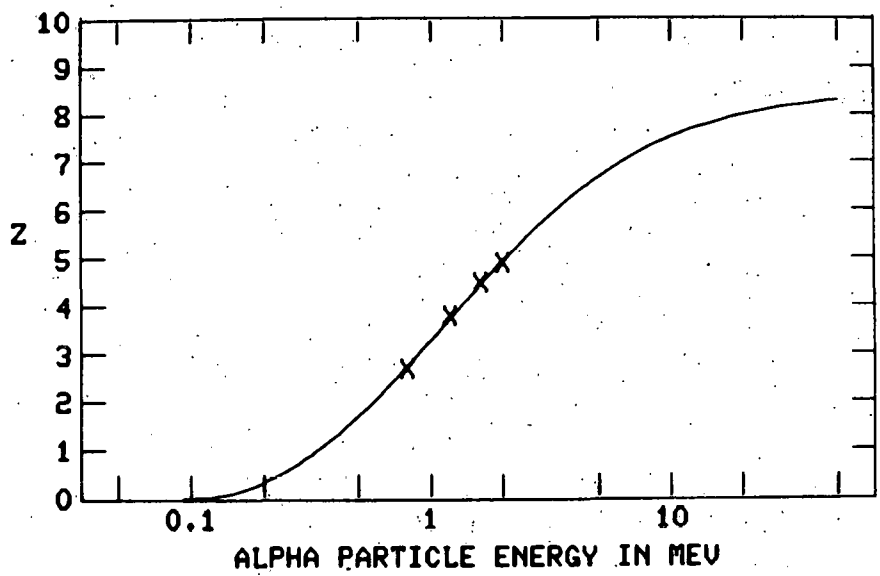

FIG. 1.--The number of effectively free electrons which an alpha particle sees in a water molecule. The points marked (x) are from fits to the data.[5] The curve is a smooth extrapolation.

The soft collision term, in first Born approximation, has the form[11-13]

$$Y_{Soft}(T,Q) = (1 + d_s \log T/T_s)S(Q) \quad . \tag{5}$$

The shape of the spectral function S(Q) and the value of the slope parameter d_s vary considerably for different media. Theory gives little guidance as to the magnitude of d_s and the shape of S(Q). Form 5 predicts,

however, a clean separation of T- and Q-dependent terms. In order to test this factorization and to find the shape of S(Q), we have solved Eq. 5 for S(Q). After extraction of the hard collision term, variation of the parameters d_s and T_s leads indeed to a universal function of Q, almost independent of T (Figure 2).

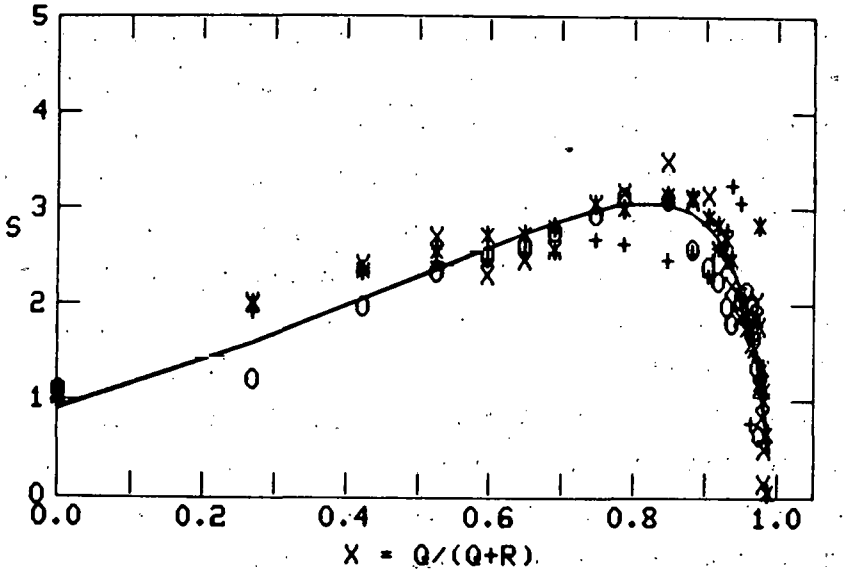

FIG. 2.--The function S(Q) which gives the soft collision term. If separation of the variables T and Q strictly holds, all points taken at different energies T should fall on a single curve. The solid curve is our parametrization.

We have expressed the function S(Q) in the form

$$S(Q) = c_s\,(a_s + x)^2\,\left(\frac{b_s}{b_s + Q}\right)^{2.5}\,, \tag{6}$$

where[10]

$$x = \frac{Q}{Q + R}\,. \tag{7}$$

This variable is only slightly different from Platzman's x. It maps the

infinite Q region into $0 \leq x \leq 1$, and also has the property that the area under the resulting Platzman plot is proportional to the ionization cross section.

Equation 6 separates the low Q and the high Q behavior and ensures the eventual $Q^{-2.5}$ behavior of S at high Q found in quantum mechanical calculations.[11-13] The values of the soft parameters in Eq. 5 are $a_s = 0.8$, $b_s = 800$ eV, $c_s = 0.9$, $d_s = 1.1$, $T_s = 0.8$ MeV. All quantities without units are dimensionless.

The convoy electrons stand out in the He^{++} data as a peak at the Q value corresponding to $v_e = v_\alpha$. There exists a considerable literature on these convoy electrons. Careful experiments[14] show a forward angular peak with a cusp-like energy dependence. This is understood quantum mechanically by the observation that an electron which gets trapped between the original molecule and the alpha particle has difficulty deciding to which partner it belongs. If it happens to move with the same, or approximately the same, velocity as the alpha particle, the latter will drag it free from its molecule without actually binding it. As for the energy dependence of the size of the convoy peak, the literature speaks only of a strongly falling energy dependence. Attempts at treating this three-body system theoretically with the Born approximation to the Faddeev equations were only partially successful.[4]

Our fits to the data were made by extracting the convoy peak at the four available energies. They confirm the falling energy behavior. Yet at lower energies, the convoys cannot increase indefinitely or there would be too many ionizations. We expect a maximal convoy response in that energy region in which the alpha-particle velocity matches the internal motion distribution of the electrons. For slower alpha particles, there will be fewer electrons to drag along.

We start by writing the convoy <u>amplitude</u> at a given alpha-particle energy (velocity) as

$$A_{cvy}(T,Q) = \frac{G_c}{\frac{m_e}{2}(v_e - v_\alpha)^2 + G_c} \quad . \tag{8}$$

This is the simplest form which a Q-dependent amplitude would have after integration over the forward angles. Even a cusp with an experimentally caused width could be matched by this form.

The convoy cross section for ionization is then obtained by taking the absolute square and multiplying by an experimental T-dependent factor:

$$Y_{cvy}(T,Q) = C_{cvy}(T) \left| \frac{G_c}{\frac{m_e}{2}(v_e - v_\alpha)^2 + G_c} \right|^2 , \tag{9}$$

with G_c = 35 eV the width of the convoy peak. We write the T-dependent factor as

$$C_{cvy}(T) = C_c \cdot \frac{T^{2.5}\, T_c^{\,2}}{(T + T_c)^{4.5}} , \tag{10}$$

with C_c = 140, T_c = 0.45 MeV.
Here the high energy part was found from fits to the convoy term extracted from the data[5] (see Figure 3). The low energy T-dependence is obtained from constraints imposed by W, the energy per ion pair (see below). We find that the convoy height grows roughly as $T^{2.5}$ at low T, obtains a maximum at T ≈ 0.45 MeV, and drops off roughly as T^{-2} at high energies. Data are only available in the high energy region, where they are consistent with our falling T-dependence.

The Auger cross section, which makes a small but characteristic contribution, is best written in the form of a Lorentzian peak with a T-dependent factor governing its height:

$$Y_{Aug}(T,Q) = C_A \log(T/1.0) \frac{G_A/\pi}{(Q - Q_A)^2 + G_A^{\,2}} , \tag{11}$$

with Q_A = 476 eV, the position of the Auger peak, G_A = 35 eV, the width of the Auger peak, and C_A = 300 eV, the overall strength of the peak.

The maximum energy that can be transferred by an alpha particle to an electron at rest in a two-body collision is given to a good approximation by

$$Q_m = 4 \frac{m_e}{m_\alpha} T_\alpha . \tag{12}$$

We observe, however, that the data are by no means cut off sharply at this energy and that they extend clearly beyond it. This is due to the fact that the target electrons are not at rest but are indeed fast moving within the molecule (internal motion). Considering the kinematics of a collision of an

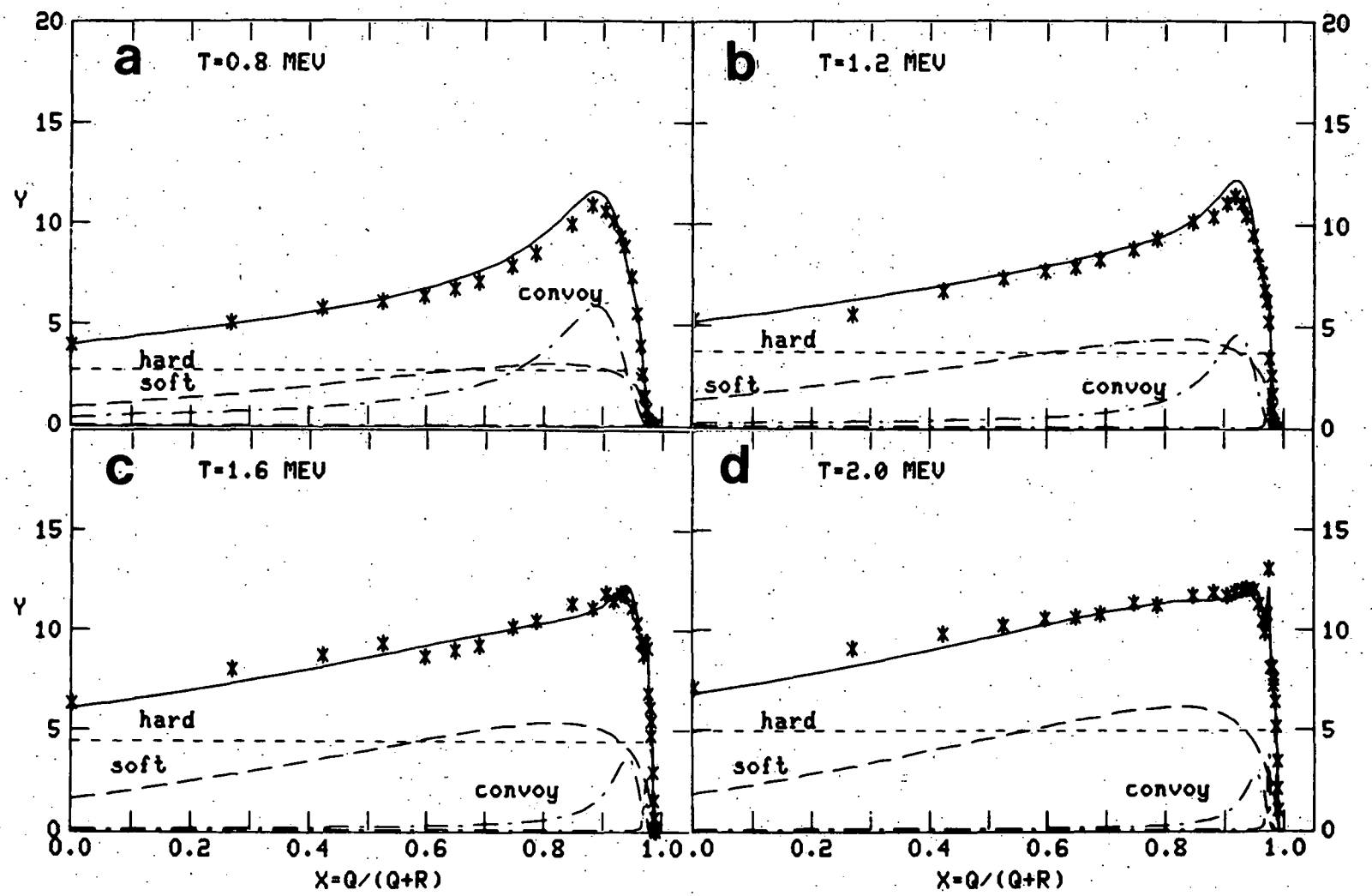

FIG. 3.--Platzman plots at four energies (T = 0.8, 1.2, 1.6, 2.0 MeV) for He^{++} ionization in water vapor. The data are from Ref. 5. The solid lines are the overall fits. Also shown are the individual components at the different energies. The ordinate on all the Platzman plots is Y(T,Q), the dimensionless Platzman ratio of actual differential cross section over the Rutherford differential cross section.

alpha particle with a moving target electron (with energy Q_t) we find that the upper end of the spectrum is smeared out over a region

$$Q = Q_m \pm \Delta Q_m \tag{13}$$

with

$$\Delta Q_m = 2\sqrt{Q_t Q_m} \quad . \tag{14}$$

The value of $Q_t = R$ is approximately correct for the outer shell electrons. In our fits, a value of $Q_t = 20$ eV worked best and was used. For the inner shell electrons, considerably higher values of Q_t would have to be used. The emission of the Auger electrons is, of course, not affected by this spreading effect as they are emitted by a very massive nucleus.

The final fits to the He^{++} data[5] together with the contributions from each term are shown in Figure 3. We first note the characteristically individual shapes in the Platzman plot of each term; especially the constant hard collision term, the slowly varying soft term, then the decreasing convoy peak at $Q = T_e$ and the sharp Auger peak at $Q = 476$ eV which can appear only for $T_\alpha > 0.9$ MeV. Finally, Figure 4 shows the high energy behavior (in Q) of the He^{++} cross section. In Figure 5, we show the He^{++} ionization cross section integrated over Q, divided by the Rutherford cross section integrated over Q as a function of log T: a Fano plot. The components are also shown.

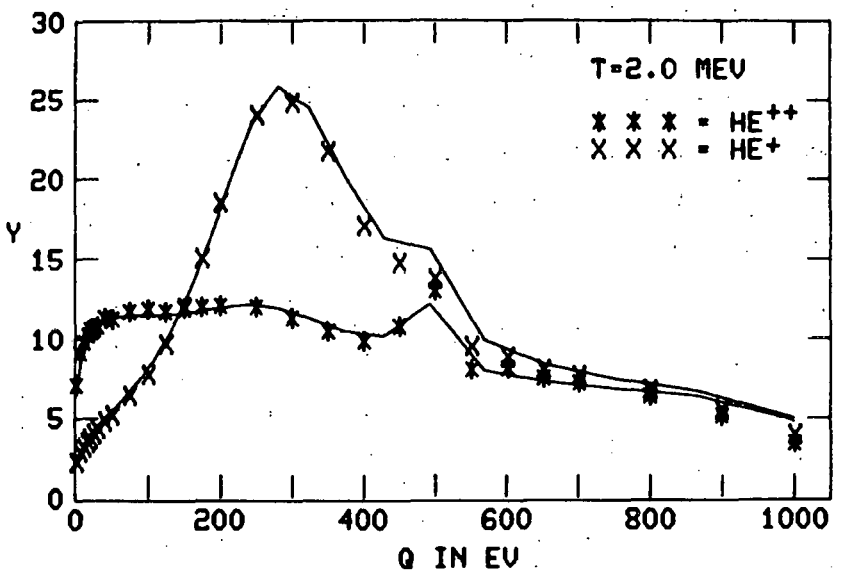

FIG. 4.--High energy behavior in Q (Kim plot) for the cross section of He^{++} and He^{+} in water vapor. Note that at high Q the two cross sections become equal as screening becomes ineffective and the stripping peak falls off. (A Kim plot has the same ordinate as a Platzman plot, but its abscissa is linear in Q.)

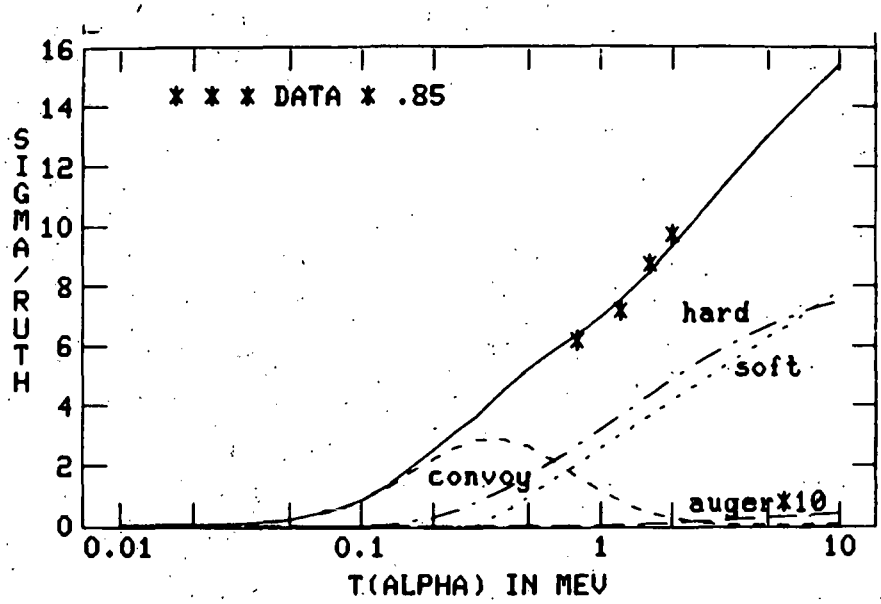

FIG. 5.--Fano plot for He^{++} ionization in water vapor. Also shown are the contributions from the different components: hard, soft, and convoy. The Auger contribution has been multiplied by a scale factor of 10 to make it visible. Note the dominance of the low energy part by the convoy term.

The He^{+} Cross Section

Toburen, Wilson and Popowich[5] have observed that the high energy part (in Q) of the He^{+} cross section has the same form as the He^{++} ionization cross section, except that at lower energies one has to add the stripping contribution and, at the lowest energies, a factor which takes into account the screening due to the extra electron has to be introduced.

We write the stripping cross section in the form

$$Y_{str}(T,Q) = C_{str} \cdot T \cdot \sqrt{T - 0.0009} \cdot \left| \frac{G_{str}}{\frac{m_e}{2}(v_e - v_\alpha)^2 + G_{str}} \right|^2 \quad . \qquad (15)$$

The square in the velocity-dependent factor is justified by the argument that it represents a stripping amplitude and gives an excellent fit to the sharp stripping peak. Here v_e and v_α are again the particle velocities. The stripping peak is so characteristic that it poses no problem to extract the parameters for its width, G_{str} = 28 eV, its strength, C_{str} = 5.1 (dimensionless), and its T-dependence as $T^{3/2}$. We have written the T-dependence in the form $T \cdot \sqrt{T - 0.0009}$ to accommodate the available W_α values[8]

which appear to diverge at T = 0.9 keV. In the high keV or MeV region, this form is indistinguishable from $T^{3/2}$. This T-dependence would lead to too large an ionization cross section at very high energies where there are no data on the cross section but where we expect W_α to remain constant. We have therefore limited the stripping cross section to 30 units in the Platzman plot, simply to guarantee that it will not affect the values of W.

We now can extract the screening function by graphing

$$f_{scr}(Q) = \frac{\sigma(He^{+}) - \sigma(str)}{\sigma(He^{++})} \quad . \tag{16}$$

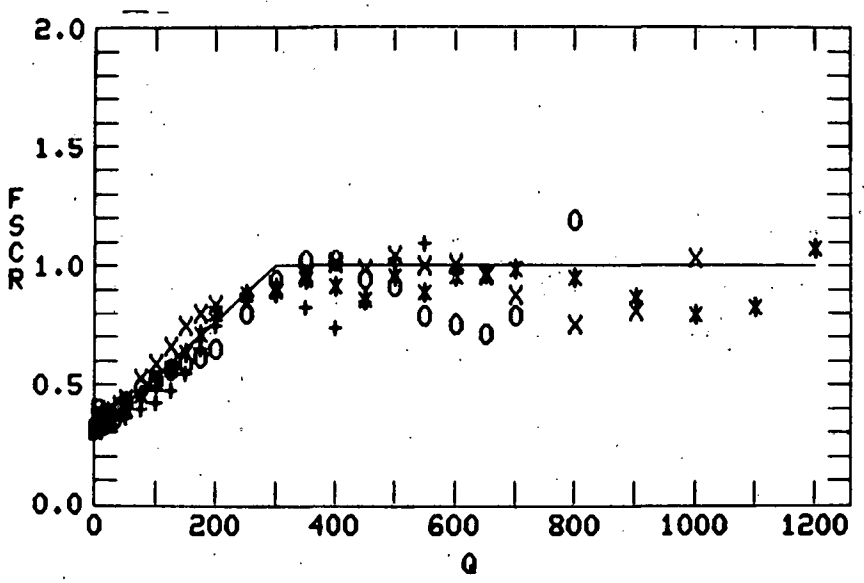

FIG. 6.--The screening function as extracted by a comparison of He^{+} with He^{++} data and subtracting the stripping part. All four energies lead to a quite similar result which means screening is essentially negligible above Q ≈ 300 eV. We have parametrized the screening effect by a function of the energy transfer Q only (solid line).

For $\sigma(He^{++})$, we use our fits to the He^{++} cross section. This is shown in Figure 6 which also indicates that f_{scr} can be taken as T-independent. From this plot, we take

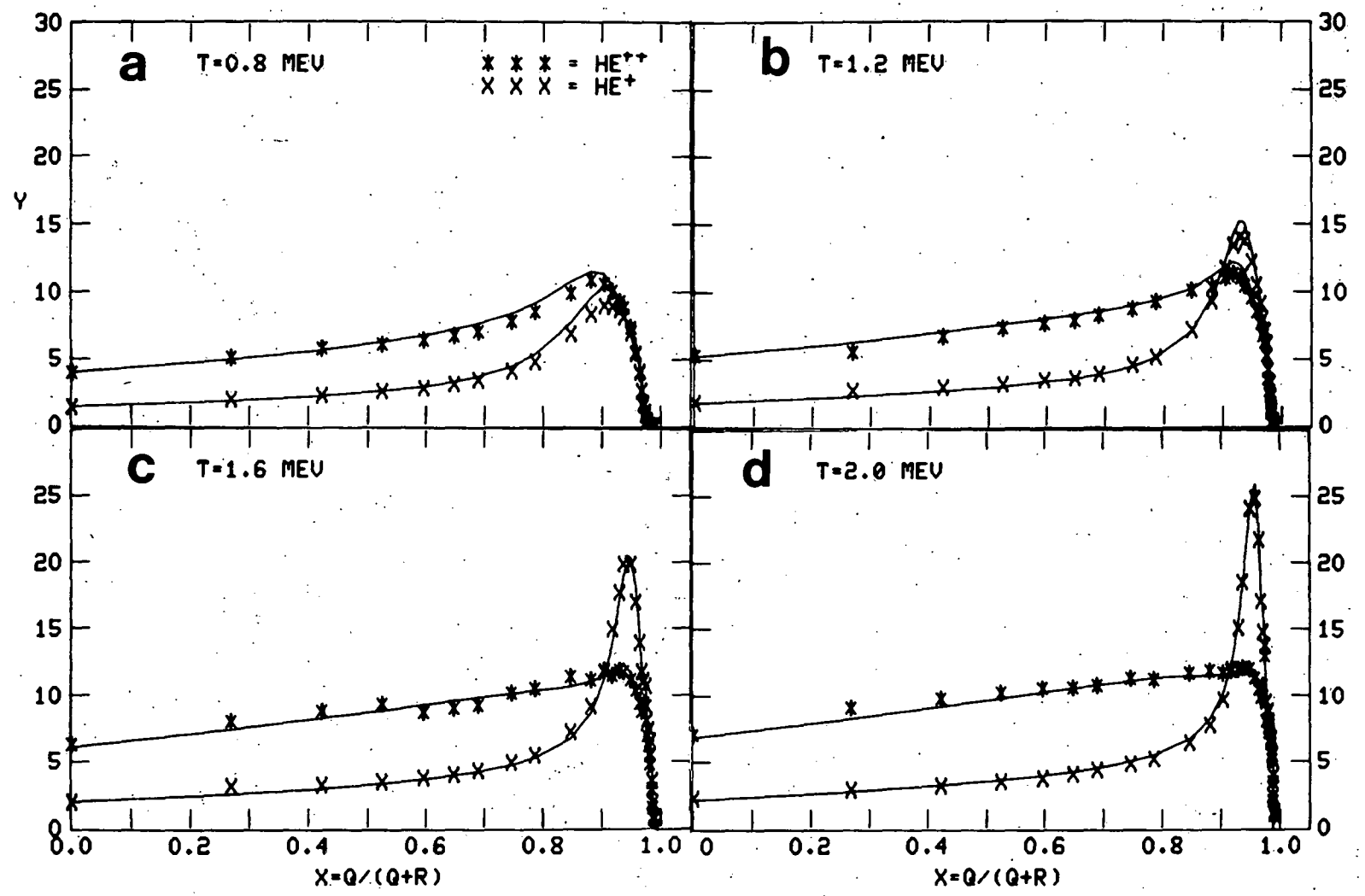

FIG. 7.--Platzman plots for He^{+} and He^{++} in water vapor at the four available energies. Note the increasing importance of the stripping peak in the He^{+} data and the decreasing evidence for the convoy term in the He^{++} data.

$$f_{scr}(Q) = \begin{cases} 0.30 + 0.70\ Q/300 & \text{for } Q < 300 \text{ eV} \\ 1.0 & \text{for } Q > 300 \text{ eV}, \end{cases} \quad (17)$$

shown as the solid line in Figure 6.

This expresses the fact that screening becomes ineffective above an energy transfer of 300 eV. It is interesting to note that at Q = 0, f_{scr} is not 0.25 but 0.30.

With this, the He^+ differential cross section reads

$$Y_{He^+}(T,Q) = f_{scr}\ Y_{He^{++}} + Y_{str}(T,Q) \quad . \quad (18)$$

This is shown in Figure 7 and compared to the data. The high energy part of the He^+ cross section is also shown in the Kim plot of Figure 4, where it is compared to the He^{++} cross section.

Charge Equilibria and the Effective Cross Section

As the alpha particle slows down in the medium, it loses charge by picking up electrons. This is a dynamic interplay between pickup and stripping. Armstrong et al.[6] have carried out measurements in solids and liquids and have found that the alpha particle establishes an equilibrium between the different charge states which depends on the alpha-particle energy only. We have accepted their measurements and their expressions for the ratios of the charge fractions:

$$F_0/F_2 = 8.1 \times 10^{-3}\ T^{-4} \quad (19)$$

$$F_1/F_2 = 0.273\ T^{-2} \quad (20)$$

To this, we add the constraint that the sum of the three charge states is 1:

$$F_0 + F_1 + F_2 = 1 \quad . \quad (21)$$

Solving the three equations (19, 20, 21), we find

$$F_2 = [1 + 8.1 \times 10^{-3}\ T^{-4} + 0.273\ T^{-2}]^{-1} \quad , \quad (22)$$

$$F_1 = 0.273\ T^{-2} \times F_2 \quad , \text{ and} \quad (23)$$

$$F_0 = 8.1 \times 10^{-3} \times T^{-4} \times F_2 \quad . \quad (24)$$

These charge fractions, shown in Figure 8, demonstrate that in the MeV region the helium ion is fully stripped. The He^+ state is important around T = 0.3 to 0.5 MeV. At lower energies, the He^0 state dominates.

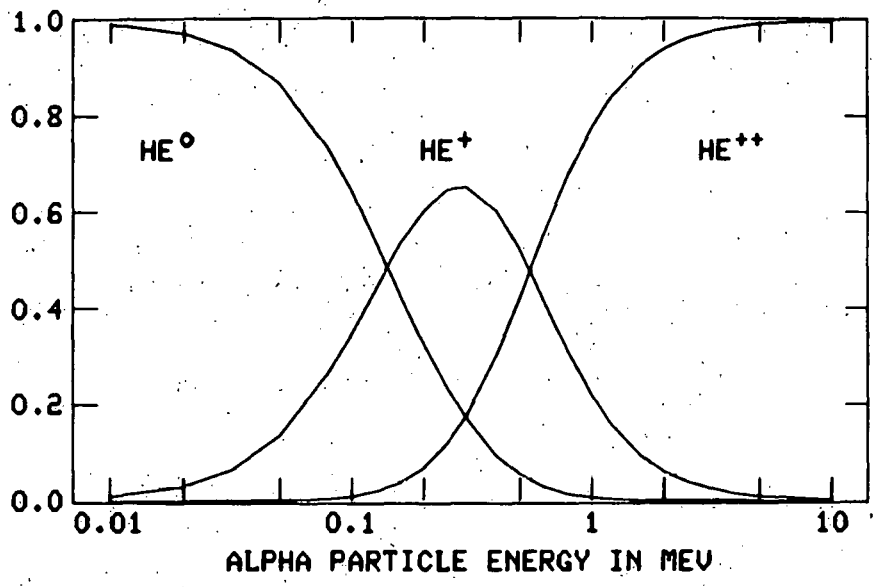

FIG. 8.--Charge fractions for alpha particles as extracted from Armstrong et al.[8] As the alpha particle loses energy, it becomes more likely to pick up one or two electrons. Thus, at high energies, the He^{++} state dominates; at the lowest energies the He^{o} state dominates. There is an intermediate energy range in which He^{+} is relevant but not dominant.

With the expressions for the charge fractions, we can now write the energy dependence of the alpha particle ionization cross section as

$$Y_{eff}(T,Q) = F_0\ Y_{He^o} + F_1\ Y_{He^+} + F_2\ Y_{He^{++}} \quad . \tag{25}$$

Before we can evaluate this expression at the lowest energies which we need, we must find an expression for the He^{o} cross section. We have no experimental information on the low energy cross section. Therefore, we have taken the He^{o} cross section as twice the stripping term established for He^{+}, plus a screened He^{++} contribution, i.e.,

$$Y_{He^o}(T,Q) = 2\ Y_{str}(T,Q) + f_{scr}\ Y_{He^{++}} \quad . \tag{26}$$

Ionization Densities

Multiplying the established Y_{eff} by the Rutherford cross section gives the effective cross section, and by further multiplication by $n = 3.34 \times 10^{22}$, the number of water molecues per cm^3, we obtain $N_{1\alpha}$ the number of primary

ionizations per micrometer per keV secondary electron energy,

$$N_{1\alpha}(T,Q) = n \left.\frac{d\sigma}{dQ}\right|_{Ruth} \cdot Y_{eff}(T,Q) \quad . \tag{27}$$

This is shown in Figure 9.

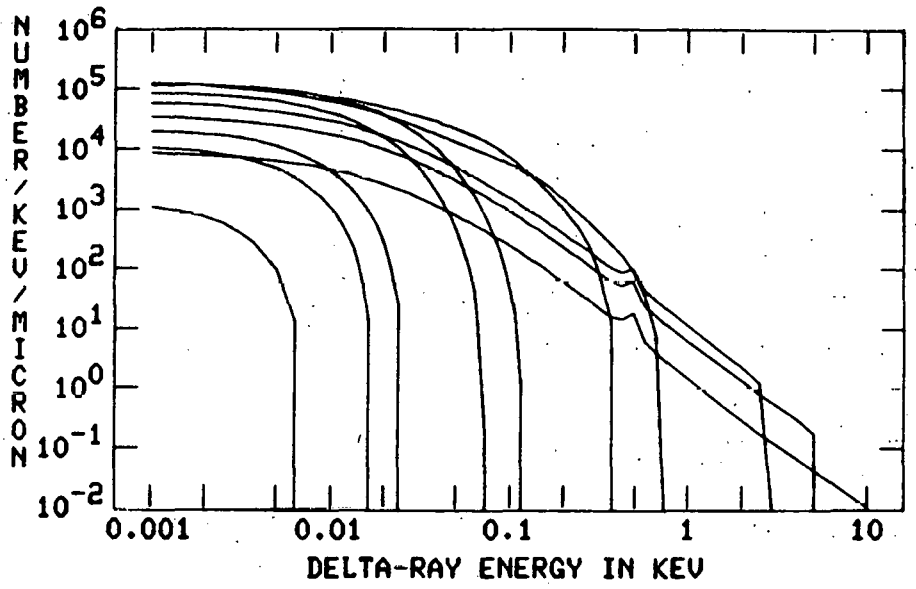

FIG. 9.--Final values for $N_{1\alpha}(T,Q)$, the number of primary ionizations on the main part of the alpha-particle track at the following energies: T = 1, 5, 10, 50, 100, 500, 1000, 5000, 10000, 50000 keV.

As in our earlier report,[1] we can now use the Wideroe[15] method to evaluate the number of secondary electrons produced by the first generation. We have,

$$N_{2\alpha}(T,Q) = \int N_{1,\alpha}(T,E')\ ND(E',Q)dE' \quad . \tag{28}$$

Since this involves merely the knocking out of an electron by an electron, we have already computed the kernel ND of this integral in our earlier work,[1]

$$ND(E,Q) = \int \frac{N_{1e}(E',Q)}{LET_e(E')}\ dE' \quad . \tag{29}$$

Here, N_{1e} and LET_e are the first order delta ray densities and LET for a beta ray. E and E' are the energies of the parent electron. By repetition of this process, we generate $N_{3\alpha}$ and $N_{4\alpha}$ and, by adding these four components, the sum $N_{\alpha,sum}(T,Q)$ of ionization densities. We are at present working on accurate numerical evaluations of the resulting integrals.

Of special interest is the total number of ionizations per micron of alpha-particle track. This is obtained by summing over all the secondary electron energies,

$$N_{i,int}(T) = \int_0^{Q_{max}(T)} N_{i\alpha}(T,Q)dQ \quad . \tag{30}$$

Finally, we can obtain the total number of ionizations caused along the alpha-particle track by integrating over the residual range of the particle. This can be converted to an energy integral with the help of the identity,

$$dx = \frac{dx}{dT}\, dT = \frac{dT}{LET_\alpha(T)} \quad . \tag{31}$$

This leads to

$$N_{\alpha,tot}(T) = \int_0^T \frac{N_{\alpha,int}(T')}{LET_\alpha(T')}\, dT' \quad . \tag{32}$$

LET and W for the Alpha Particle

To compute $N_{\alpha,tot}$ we need the linear energy transfer LET_α for the alpha particle in the interesting energy region (four orders of magnitude). For this, we found the data of Mateson et al.[16] and of Palmer et al.[17] on water, ice, and water vapor most useful. In Figure 10, we show the alpha-particle LET over a linear energy scale and in Figure 11 over a log E scale. The log E scale is more compatible with our needs; the linear scale is more commensurate with the available data. The figures also show the Bethe-Bloch[2,3] fits and two simple representations which we found useful in handling the LET data in our programs. For water, we have used

$$LET_{liq,\alpha}(T) = \frac{L_{max}(2 + C_\ell \cdot T_{max})}{T_{max} + C_\ell \cdot T \cdot T_{max} + T^2/T_{max}} \quad , \tag{33}$$

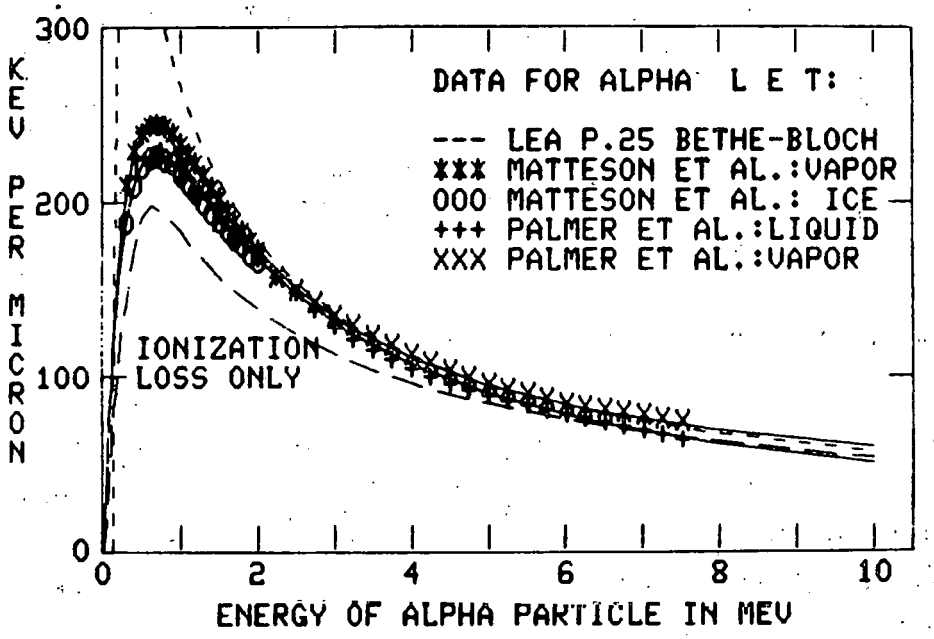

FIG. 10.--Linear Energy Transfer for an alpha particle in water or water vapor. The data are from Matteson et al.[16] and Palmer et al.[17] The upper solid line shows our three-parameter fit to the vapor data. The dashed line is the Bethe-Bloch expression. The long-dashed line shows the energy loss due to ionization loss alone.

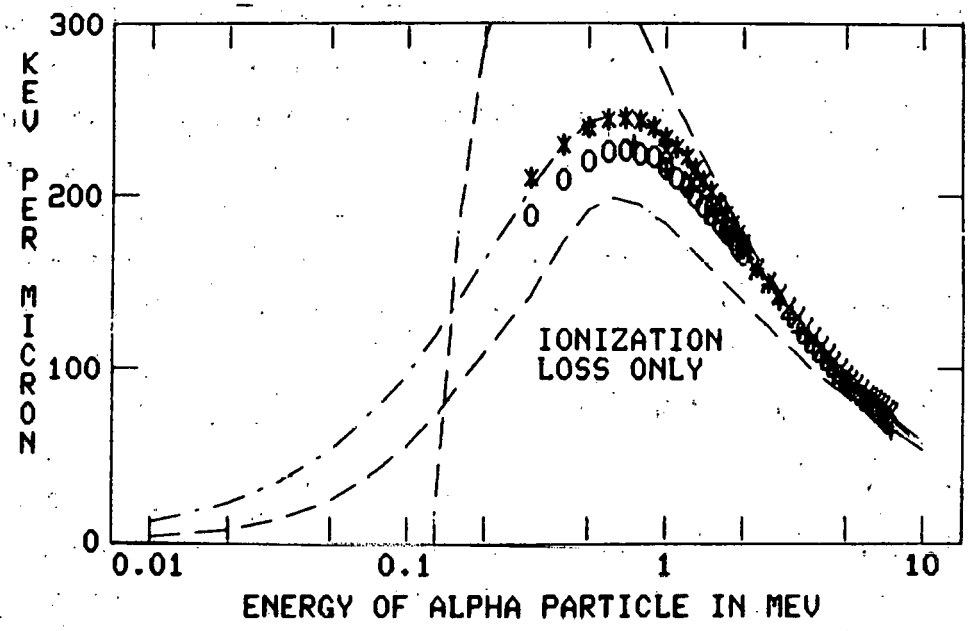

FIG. 11.--The same LET expressions and data as Figure 10, but on a log T abscissa. This emphasizes the low energy decades and shows the considerable extrapolation involved.

with $C_\ell = 0.0022\ MeV^{-1}$, $L_{max} = 227$ keV/μm at $T_{max} = 685$ keV.
For water vapor, we have used

$$LET_{vap,\alpha}(T) = \frac{L_{max}(2 + C_v \cdot T_{max})T(1 + B_v \cdot T)}{T_{max} + C_v \cdot T_{max} \cdot T + T^2/T_{max}} \quad , \tag{34}$$

with $C_v = 0.0015\ MeV^{-1}$, $B_v = 4.10^{-5}$ MeV and $L_{max} = 241$ keV/μm at $T_{max} = 630$ keV.
These expressions fit the available data well within the experimental accuracy, and they can be used to extrapolate reasonably to energies below the data. Three-parameter fits to LET values have been made by Brice.[18]

Finally, we have evaluated the energy spent per ion pair created, by evaluating

$$W(T) = T/N_{tot}(T) \tag{35}$$

with $N_{tot}(T)$ taken from Eq. 32. The evaluation of this quantity W is preliminary but has proved most useful in several aspects. At high energies (T > 1 MeV), it is of interest to note that both the shape and the value of the computed W agree with the experimental values. This is after the renormalization of the Toburen data discussed earlier. Unfortunately, we have no values of W for alpha particles in water and thus had to compare with data on TE-gas. At energies below T = 0.3 MeV, we have no data on ionization cross sections nor on LET_α. We are able to extend our LET curves and our cross section expressions in a consistent way by the use of the following identity,

$$LET_\alpha(T) = N_{\alpha,int}(T) \cdot \frac{d}{dT}\left(\frac{T}{W}\right) \quad . \tag{36}$$

This has been obtained by differentiating the equation $N_{tot} = T/W$ and using Eq. 32 for N_{tot}. This identity is a local one in that it holds for each T value. It puts severe restrictions on the $N_{\alpha,int}$ expression at the higher energies, where we have data for both LET and W. At the lowest energies, we have used this expression to extend our LET fit in such a way that it remained consistent with the data for W. This has influenced specifically our choice of the low energy part of the terms for the stripping and convoy electrons.

Discussion

Our fits, which have been constructed as superpositions of the different incoherent components of the differential cross sections, are accurate representations of the entire spectrum of first order electrons produced by the alpha particle, at least as far as the single differential cross section is concerned. In our analysis, the hard collisions and the soft or glancing collisions, which have been the main contributors in earlier constructions, decrease at lower alpha-particle energies and become negligible in the low energy range. The low energy part of the He^{++} cross section is dominated by the so-called convoy term, which at low energy is really representative of the sum of all the three-body interactions between the water molecule, the alpha particle and the relevant electron (see the Fano plot in Figure 5). For He^{+} and He^{o}, the stripping term becomes important, and because the charge equilibrium between stripping and pickup favors He^{o} at the lowest energies, this stripping term is the most important one at the low energy end of the spectrum.

Our construction has permitted us to compute the ionization densities on the main track and (after more carefully evaluating the relevant integrals) also on the secondary electron tracks down to fourth order.

Acknowledgment

The authors gratefully acknowledge numerous and most helpful discussions with Dr. Mitio Inokuti and Dr. Yong-Ki Kim.

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THE LINING CELLS ON NORMAL HUMAN VERTEBRAL BONE SURFACES

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Thoracic vertebrae from two individuals with no bone disease were studied with the electron microscope to determine cell morphology in relation to bone mineral. The work was undertaken to determine if cell morphology or spatial relationships between the bone lining cells and bone mineral could account for the relative infrequency of bone tumors which arise at this site following radium intake, when compared with other sites, such as the head of the femur. Cells lining the vertebral mineral were found to be generally rounded in appearance with varied numbers of cytoplasmic granules, and they appeared to have a high density per unit of surface area. These features contrasted with the single layer of flattened cells characteristic of the bone lining cells of the femur. A tentative discussion of the reasons for the relative infrequency of tumors in the vertebrae following radium acquisition is presented.

Introduction

Many approaches have been tried to uncover the mechanism of bone tumor induction by alpha-emitting radionuclides. The histological approach of studying tissue response in radium dial painters was utilized first by Dr. Harrison Martland in 1925.[1] His observations have provided a firm scientific foundation for further study. Our electron microscope work of analyzing bone surfaces in control and radium-exposed individuals has extended histological analysis to the level of the individual cells. A previous study of cortical bone samples from an age-matched control and a radium dial-painter compared the histology and location of cells in closest proximity to the endosteal bone surface at the distal end of the femur.[2] To the best of our knowledge, the present report is the first electron microscope study made on trabecular bone from the vertebrae.

It has been suggested that bone tumor induction may be a direct effect of damage to osteogenic cells, particularly on endosteal surfaces.[3] Usually by the time bone tumors are diagnosed, the precise site of origin is uncertain, but tumors are thought to arise in both cortical and trabecular bone, most frequently at the ends of the long bones. It has always been a mystery as to why so few tumors appear in the vertebrae which often contain more radium per gram of bone than other sites where tumors more frequently arise, at least for long periods after intake (up to about 20 years).[4] The present study was initiated to determine if important differences at the individual cell level

†Deceased, February 24, 1982.

could be seen to account for this apparent anomaly. In particular, we set out to determine whether the spatial arrangement of cells with reference to the known source of radioactivity (bone mineral) in the vertebrae was different from the earlier work which we published for normal control cortical bone.[2]

In the present study, control trabecular bone was sampled at autopsy from the eighth thoracic vertebrae of two individuals.

Materials and Methods

Case Histories

The first control subject (A79-146) was a 53-year-old Caucasian female who had undergone cardiac surgery and died in May of 1979 as a result of heart failure and pneumonia. She had no history of bone-related problems.

The other control individual (A79-149) was a 58-year-old Caucasian male who died of septic shock, also in May of 1979, as a result of oat cell carcinoma of the lungs. He had no history of bone-related problems.

A sample of trabecular bone was taken from the eighth thoracic vertebra of each of these control individuals.

EM Processing

The specimens were collected at 13 and 20 hr, respectively, postmortem and placed in phosphate-buffered 3% glutaraldehyde for fixation. Longitudinal sections were obtained from the center of the vertebral body in each case during the autopsy. Following fixation, slices of tissue 2 mm thick were cut from the center of the longitudinal sections using a Foredom Series DD saw. From these pieces, 1 to 2 mm^3 samples were taken and processed in the same manner as previously described for undecalcified bone samples.[2]

Briefly, the samples were post-fixed in osmium tetroxide, dehydrated through a series of alcohols that gradually increased to 100% ethanol, at which point they were placed in propylene oxide for final dehydration. Gradual infiltration was carried out in Epon followed by polymerization. The blocks containing the samples were trimmed in preparation for sectioning on the Huxley ultramicrotome. Sections appearing in the gold portion of the spectrum (90-150 nm thick) were cut and picked up on parlodion-coated grids, for stability, prior to staining in uranyl acetate and lead citrate. The finished material was viewed and photographed in a Siemens Type 1A Elmiskop transmission electron microscope.

Results

Control Vertebrae

In this trabecular bone study, particular emphasis was placed on documenting the morphology of cells closest to the trabecular bone mineral where radium-226 deposits. Figure 1 (control A79-149) shows an area where only the elongated oval nuclei of two bone lining cells may be seen within the layer covering the collagen edge of bone mineral. The marginated chromatin of the nuclei and the thin, barely distinguishable cytoplasm with few intercellular vesicles was typical of the type of cells lining bone seen overlying collagen on resting bone surfaces.

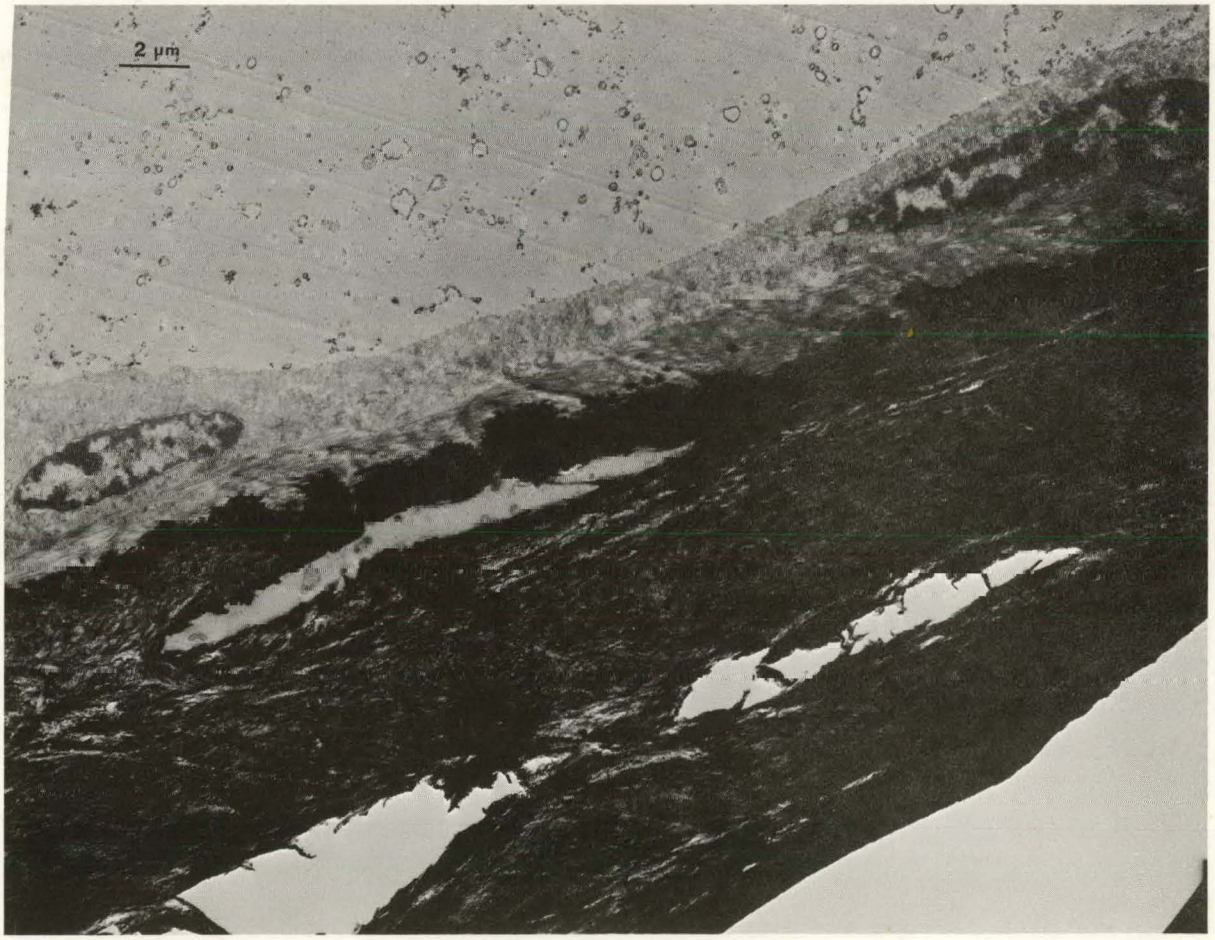

FIG. 1.--An electron micrograph of a portion of vertebral bone showing two elongated cells separated from bone mineral by a thin layer of collagen.

In Figure 2, from vertebra A79-146, a column of cellular marrow is seen edged by the thin cytoplasm of reticular cells. This column is squeezed between two large empty spaces which were filled with fat deposits prior to its extraction during processing. A layer of collagen is seen interposed between the black-appearing mineral at the bottom of the picture and cells lining bone. Part of the thin nucleus of one of these lining cells can be seen in the lower left-hand corner. Thin elongated cells with a fibroblastic appearance were found to be prevalent along the trabecular bone surfaces in both of the vertebrae. The overall impression was that in the control vertebrae, there was always evidence of cellular presence overlying collagen

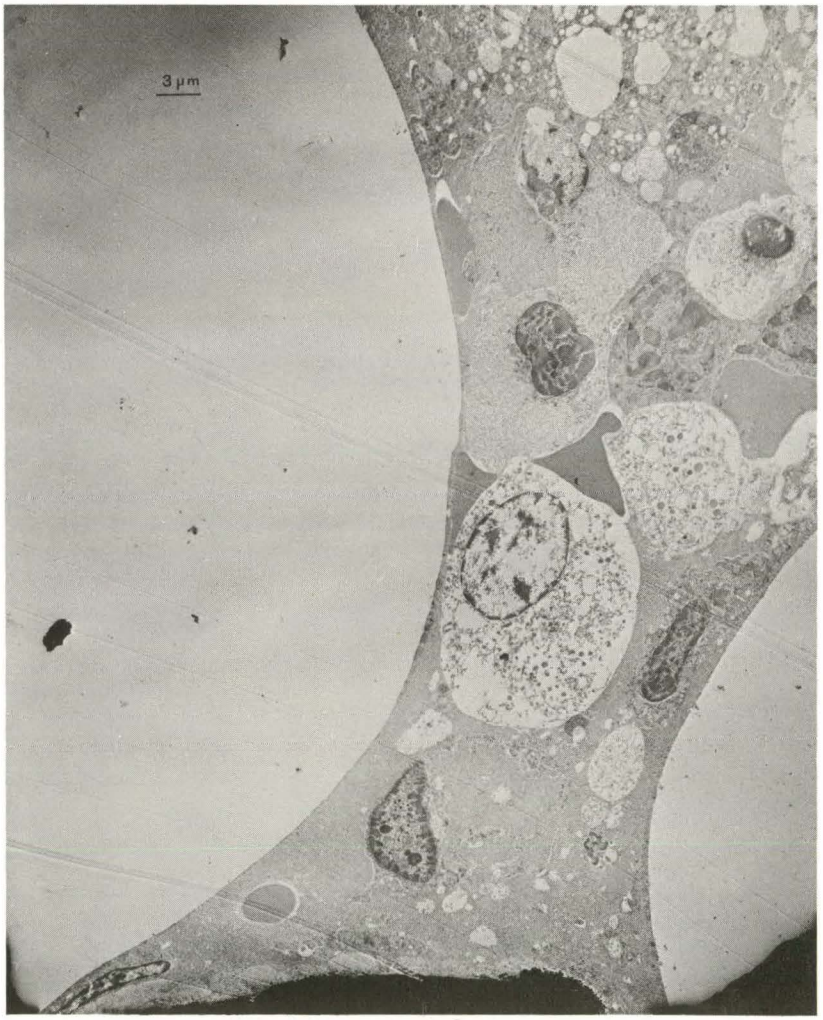

FIG. 2.--An electron micrograph of a portion of marrow attached to bone mineral (bottom) showing a wide range of marrow cells with two cells having elongated nuclei close to the bone mineral.

in the region of the cell layer lining bone. The cells in this layer tended to be more densely packed than those observed in the cortical bone from the femur studied previously.[2]

Figure 3 is a low-power view showing many cells within a few microns of the edge of bone mineral. Only one of these (top right), however, assumes the typical elongated appearance of the resting cells lining bone seen predominantly on the endosteum of cortical bone described earlier.[2] The more rounded appearance of most of the cell nuclei observed here, together with the large number of cytoplasmic granules, is suggestive of more active cells in the marrow, which may not be involved with the remodelling of bone mineral.

FIG. 3.--An electron micrograph of cells along the surface of bone mineral. Most of the cells have more rounded nuclei than those seen in Fig. 1 and have many cytoplasmic granules.

Discussion

Among 69 bone sarcomas in the American human radium cases, only one was reported in the vertebral column; it was described as a "fibrosarcoma of the lumbosacral spine" (case 03-213).[5] By contrast, over 50% of the bone tumors were found in the long bones with the ends of the bones being the predominant sites. The term "ends of the long bones" is taken to include both cortical bone and trabecular bone, since it is rare that the precise origin of the tumor can be identified. It is, however, known that maximum growth and remodelling of the long bones take place at these sites with the resultant heavy deposition of radium in growing bone. Most of the radium dial painters were in their late teens or early twenties at the time they acquired their radium, so it is perhaps not surprising that these are favored sites in this population. However, trabecular bone in the vertebrae also shows a high rate of turnover, and it is, therefore, surprising that few tumors have been found there. In this connection, it is interesting to note that in the Utah beagles injected with radium, 26% of the tumors arise in the vertebrae. The reason for this species difference has been discussed elsewhere and the difference in the distribution in weight bearing in the two species has been advanced as a possible explanation.[6] A priori one might expect this to be associated with structural and morphological differences. The present work was confined to the human skeleton to see if differences in the nature of the cells at risk could be identified between the vertebrae studied here and the femora from normal control individuals, which had previously been studied by ourselves and by others.[2,7] The main difference which we observed between the two sites was the increased number of cells per unit of bone surface area in the vertebrae when compared with both cortical bone and with trabecular bone at the head of the femur. In addition, many of the cells on the vertebral surface could not be distinguished from cells commonly seen throughout the marrow. Figures 3 and 4 illustrate this point. Figure 3 shows the cells lining bone mineral and Figure 4 is taken from the middle of the marrow. The granulocytic appearance of many of the cells in both pictures is noteworthy. Although it is not possible to know if the cells seen here are of osteogenic origin, the typical surface cells certainly appear different from the more regular single layer of flattened cells described previously for the end of the femur in both cortical and trabecular areas. Marrow cells in general are known to reproduce very rapidly. Could it be that in the vertebrae, the bone-forming cells directly

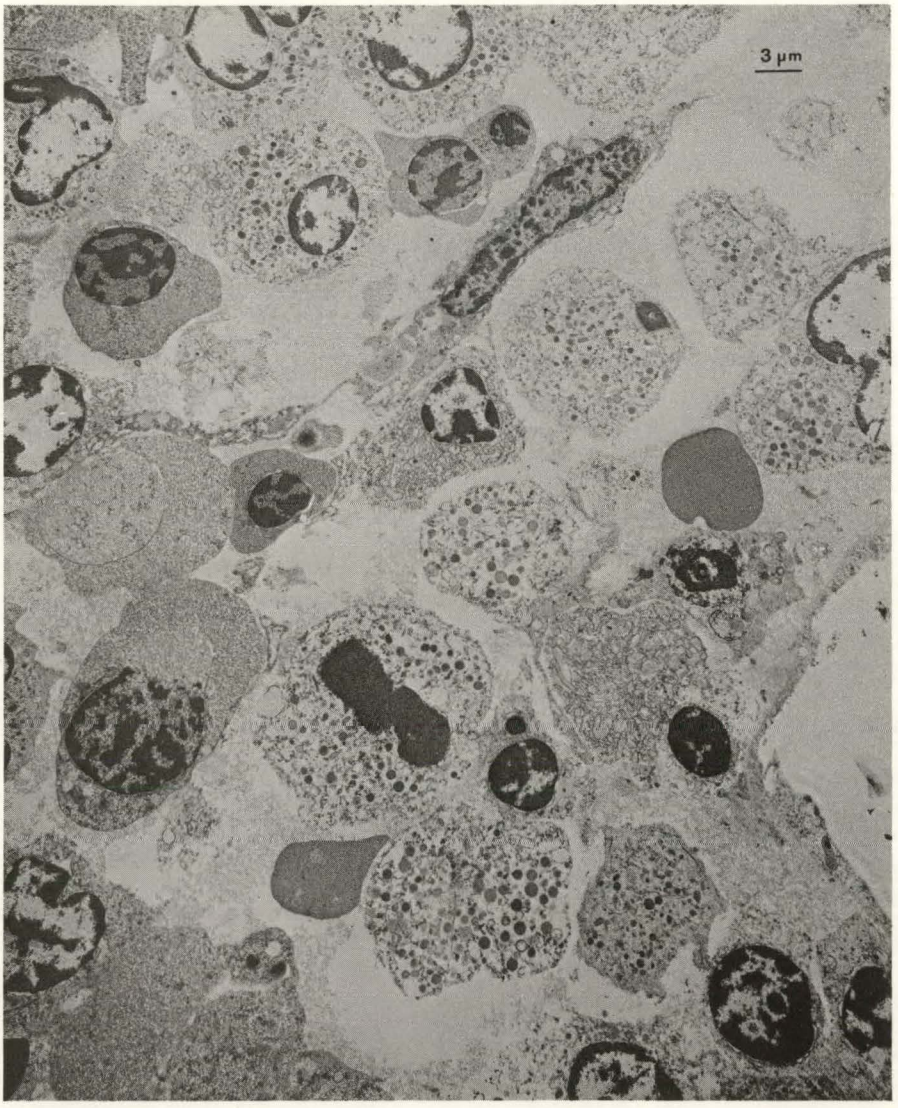

FIG. 4.--A typical electron micrograph of marrow cells, many of which are similar in appearance to those seen on bone mineral surfaces in Fig. 3.

adjacent to bone mineral receive such a high dose that they are killed and need quick replacement? Nearby cells which are called upon to divide soon after being severely damaged also may have no time for repair and preferentially die. Hence, the balance between cell death and malignancy may be weighted on the side of cell death with very fast replacement from the wealth of nearby precursors resulting in a rapid fibrotic buildup. Differences in cell shape and cell types as evidenced from the morphological differences we have observed here may be equally, or even more, important in determining the ultimate fate of the individual cells.

In conclusion, we have observed differences in cell shape, cell density and cell types between those cells which line bone surfaces of the trabeculae in vertebral bone and those observed in the head of the femur by ourselves and by others. Typically, the head of the femur shows a single or double layer of flattened cells separated by a 1 to 2 μm layer of collagen from bone mineral. In the vertebrae, the cells appear to have more rounded nuclei, contain more cytoplasmic granules and are more densely packed along the bone surface. At present, we can only speculate about the importance of these differences in determining oncogenic potential.

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CELL SURVIVAL OF HUMAN TUMOR CELLS COMPARED WITH NORMAL FIBROBLASTS FOLLOWING ^{60}Co GAMMA IRRADIATION

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Three tumor cell lines, two of which were shown to be HeLa cells, were irradiated with ^{60}Co gamma irradiation, together with two cell cultures of normal human diploid fibroblasts. Cell survival was studied in three different experiments over a dose range of 2 to 14 gray. All the tumor cell lines showed a very wide shoulder in the dose response curves in contrast to the extremely narrow shoulder of the normal fibroblasts. In addition, the D_o values for the tumor cell lines were somewhat greater. These two characteristics of the dose response curves resulted in up to 2 orders of magnitude less sensitivity for cell inactivation of HeLa cells when compared with normal cells at high doses (10 gray). Because of these large differences, the extrapolation of results from the irradiation of HeLa cells concerning the mechanisms of normal cell killing should be interpreted with great caution.

Introduction

In a previous paper,[1] we showed that a human bone tumor cell line (TE-85) was more resistant than normal human fibroblasts to cell inactivation by alpha irradiation. The purpose of the work described here was to extend these observations to see (1) if these same human tumor cells (TE-85) were also more resistant than normal fibroblasts to gamma irradiation and (2) to examine the response of other tumor cells to gamma irradiation to see if tumor cells in general were more resistant to cellular inactivation than normal cells. This work assumed special significance because of a recent publication which purported to show "evidence for lack of a threshold dose for lethality to human cells."[2] This report dealt with the gamma irradiation of T-1 cells which were originally established from a normal male human kidney now known to be of tumor cell origin (HeLa).[3] The question, therefore, arose as to whether or not normal human cells behaved similarly and whether the interpretation of mechanisms of cell killing developed for cell survival for tumor cells could be carried over to normal cells.

In the work described here, three human tumor cell lines and two normal human cell cultures of different origin were irradiated with gamma rays from a ^{60}Co gamma irradiation facility. The survival following doses ranging from 2 to 14 gray was determined by the usual colony assay method.[4] The surviving fraction is expressed as the ratio of the number of colonies formed following

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irradiation to the number formed in unirradiated controls following the same period of incubation.

Materials and Methods

Cell Cultures

Two normal fibroblastic cultures, KD and NFS-1, were tested. KD was initiated by Dr. Day from a skin biopsy sample taken from the lip of a healthy adult female and kindly sent to us by Dr. Takeo Kakunaga, National Cancer Institute. NFS-1 was established from normal human foreskin and was obtained from Dr. B. Casto, then at Bio-Labs, Inc.* Both cell cultures were confirmed to be normal human diploid fibroblasts with normal chromosomes. The passage numbers for both cultures were between 20 and 24 at the time of irradiation. The osteosarcoma cell line, TE-85, was provided by Contract E-73-2001-NO1 with the Special Virus Program, NIH, PHS, through the courtesy of Dr. W. A. Nelson-Rees. TE-85 was established from an osteosarcoma of the right distal femur in a 13-year-old female Caucasian. The two HeLa sub-strains used in this experiment were RPMI-41 and CCL-5. RPMI-41 was originally established in 1959 from an osteogenic sarcoma in the popliteal fossa of the left knee of a 15-year-old male at Roswell Park Memorial Institute. It has since been identified as a HeLa strain.† CCL-5, originally established from a human embryonic lung, has also been identified as a HeLa strain. Table 1 shows further details of the characteristics of the cell cultures used. All cell lines were grown in Eagle's basal medium (GIBCO) supplemented with 10% fetal bovine serum (Reheis), 1% L-glutamine and 1% gentamicin, in 75-cm^2 Falcon T-flasks. The cells were fed twice weekly. Normal fibroblastic cells were transferred following trypsinization (0.01% trypsin in calcium- and magnesium-free phosphate-buffered saline) when nearly confluent. TE-85, CCL-5 and RPMI-41 were transferred after detaching with a mixture of trypsin and EDTA at confluence. About 24 hr prior to irradiation, five 25-cm^2 Falcon T-flasks per cell line per dose were seeded with enough cells to yield 60 colonies per flask after irradiation, as estimated from preliminary experiments. About 2 hr prior to irradiation, the flasks were filled with complete media and stood

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†W. A. Nelson-Rees, personal communication. See also Ref. 5.

Table 1. Characteristics of cell cultures.

Designation	Passage No.	Morphology	No. chromosomes Range / Modal	Y-Chromosome	G6PD	Remarks
NFS-1	23	Fibro	43-46 / 46	Present	Type B	Diploid Human male
KD	18	Fibro	40-46 / 46	Absent	Type B	Diploid Human female
CCL-5 (HeLa)	Unknown	Epithelial	--	Absent	Type A	Aneuploid Human female
RPMI-41 (HeLa)	> 100	Epithelial	50-62	Absent	Type A	Aneuploid Human female
TE-85	6-10	Epithelial	50-59 / 54	Absent	Type A	Aneuploid Human female

Note: Most of this information was compiled from work carried out by Dr. W. A. Nelson-Rees (personal communication).

on end in the incubator. Thirty minutes before the first irradiation, the flasks were packed in an aseptic styrofoam box and were transported to the gamma-ray facility. The flasks remained in the insulated box at all times except during irradiation. After the completion of the irradiation, the flasks were returned to the laboratory. Each flask was removed from the box, wiped down with 70% alcohol and the excess medium was aspirated off. The flasks were returned to the incubator and left undisturbed for 9 days. The cells were then rinsed with PBS, fixed in methyl alcohol for 20 min, stained with Giemsa for at least 40 min, and washed twice with distilled water. The colonies were counted by eye, the counts being double-checked, using the stereo microscope. The 50-cell-per-colony rule was applied. The plating efficiency was expressed as a percentage of the average number of colonies in the unirradiated controls. The surviving fraction was expressed as a fraction of the control plating efficiency.

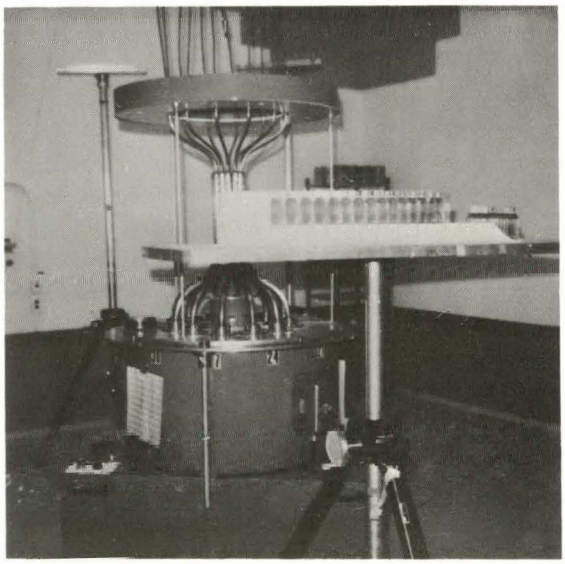

FIG. 1.--^{60}Co irradiation facility with the flasks in place for irradiation.

Irradiation

Figures 1 and 2 illustrate how the cells were irradiated in 25-cm^2 T-flasks by gamma rays from a ^{60}Co unit at dose rates of 0.75 to 0.87 gray/min. Immediately prior to irradiation, the flasks were positioned along the Lucite barrier as seen in Figures 1 and 2 so that the flask surface with the cells attached was closest to the source. Fifteen flasks were positioned

in each arc formed by the Lucite barriers. The flasks were irradiated for different times, which varied between about 2 ½ and 18 min, to give the required absorbed doses of 2 to 14 gray.

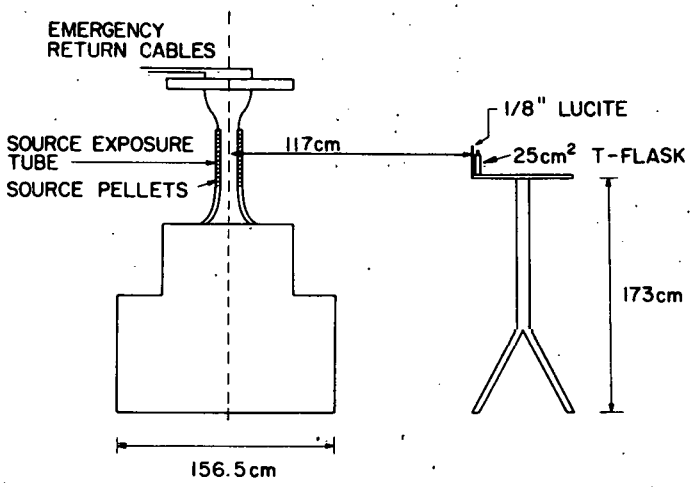

FIG. 2.--Diagrammatic representation of the setup shown in Fig. 1, indicating the relevant dimensions.

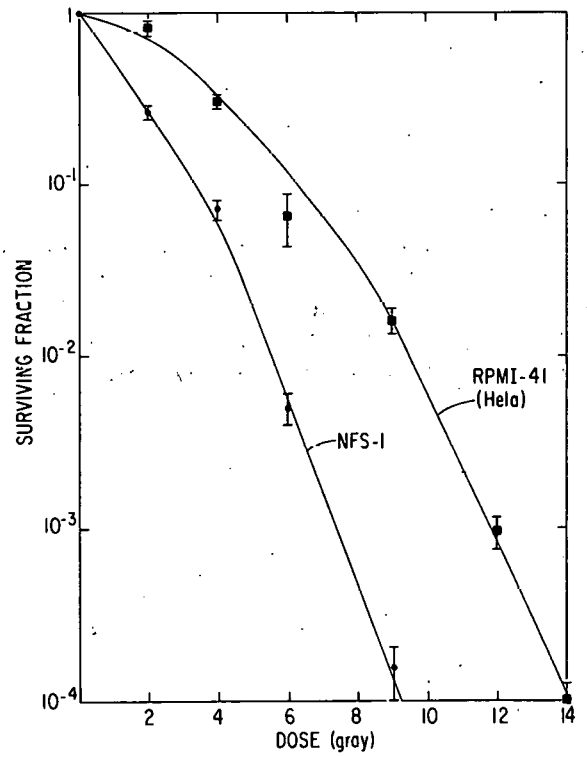

FIG. 3.--Survival curves of RPMI-41 (HeLa) cells and NFS-1 (normal fibroblasts) following ^{60}Co gamma-ray irradiation. The plating efficiences of these cultures were 75% and 11%, respectively.

Results

The dose-response data for the inactivation of the tumor cells RPMI-41 (HeLa) and the normal fibroblastic cell culture (NFS-1) are shown in Figure 3. Each error bar represents the standard error of the mean value obtained in three separate experiments. Each experiment involved the irradiation of 5 flasks at each dose level. Since these two cell cultures were studied more thoroughly than the other cell cultures, extending down to a survival of 10^{-4}, the results are presented in a separate graph. Figure 4 shows the survival for the three other cell cultures: CCL-5 (HeLa), TE-85 (osteosarcoma) and KD (normal fibroblasts). The slopes of the exponential portions of the survival curves were determined to give values for D_o for the different cell cultures as tabulated in Table 2.

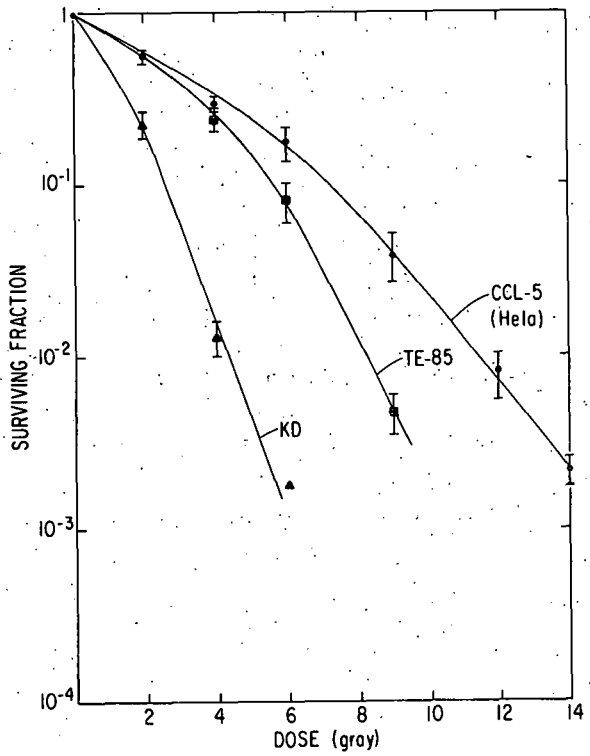

FIG. 4.--Survival curves of CCL-5 (HeLa), TE-85 (osteosarcoma) and KD (normal fibroblasts) following ^{60}Co gamma-ray irradiation. The plating efficiencies of these cultures were 33%, 22% and 16%, respectively.

Table 2. Values of D_o for different cell cultures.[a]

Cell cultures	Designation	Gray
Normal fibroblasts	KD	0.8
	NFS-1	0.8
HeLa cells	CCL-5	1.7
	RPMI-41	1.0
Osteosarcoma cells	TE-85	1.0

[a] D_o is defined as the absolute value of the reciprocal of the slope of that portion of the survival curve which is plotted as a straight line (the high dose portion of the curve), i.e., $D_o = -1/\lambda$, where λ is the slope.

Discussion

As seen in Figures 3 and 4, all the tumor cell lines studied, RPMI-41 (HeLa), CCL-5 (HeLa) and TE-85 (osteosarcoma), showed an increased survival over the normal cell cultures (NFS-1 and KD). In the experiment where we have most data (Figure 3), the survival is 1 to 2 orders of magnitude greater for the tumor cells at 6 and 9 gray than for the normal human fibroblasts. At low doses, the tumor cells show the usual shoulder on the dose response curve which has been widely commented on in previous publications concerned with cell survival curves.[6] The survival curve for the normal human fibroblasts has a much narrower shoulder and a steeper dose response.

Of all the human cell lines examined for cell survival, perhaps HeLa cells have been studied most. Different HeLa sublines have been reported to have D_o's of 1.0 and 1.3 gray.[7] We obtained corresponding values of 1.0 and 1.7 gray for RPMI-41 (HeLa) and CCL-5 (HeLa), respectively. The reason for this wide discrepancy between our two cultures is not known. The plating efficiencies were admittedly higher for RPMI-41 (75%) than for CCL-5 (33%), but this would not be expected to account for such a large difference in values of D_o[7] since at the high doses where the survival curve becomes exponential, more than 10^3 cells were plated. The similarity in the D_o values

we obtained for the two normal fibroblast cultures (0.8 gray) is perhaps fortuitous; however, the much narrower shoulder or even lack of a shoulder appears to be a feature which has previously been observed for freshly cultured fibroblasts.[8,9]

Cox and Masson[8] showed unshouldered survival curves with D_o values of 0.75 to 1.1 gray for 250 kV x rays and 1.0 to 1.3 gray for ^{60}Co gamma irradiation for freshly cultured human fibroblasts when they were in passages 6 to 25. A slight shoulder was seen to develop with increased cell generation. The cells we studied here were in passages 20 to 24.

Another factor which might be expected to modify the shape of the dose response is the relative growth rate of the cells. We therefore decided to study the pattern of growth in the RPMI-41 (HeLa) and the normal (NFS-1) cell cultures. Figure 5 shows the doubling time of the cells to be about 24 hr over the logarithmic growth phase for both cell cultures.

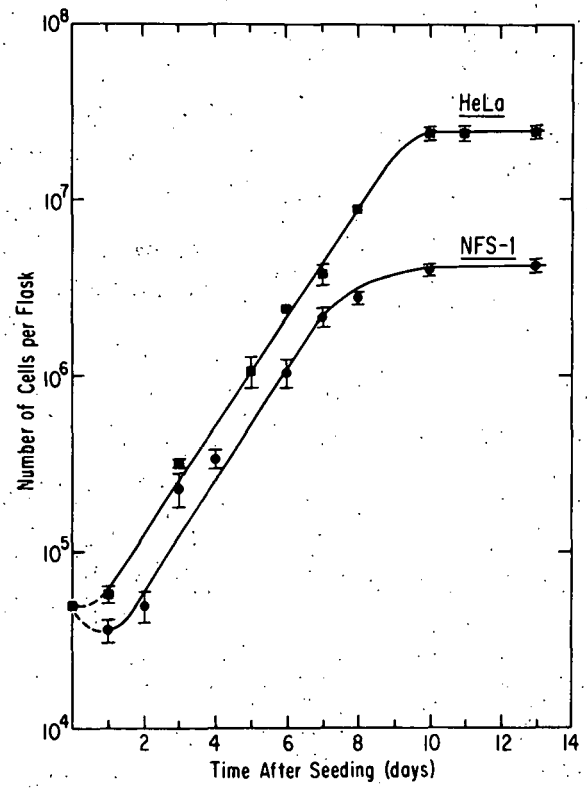

FIG. 5.--Growth of RPMI-41 (HeLa) cells and NFS-1 (normal fibroblasts). Note that the rate of logarithmic growth is approximately the same for both cultures, but that the normal cells saturate at a much lower cell density than the tumor cells.

It is often supposed that tumor cells grow more rapidly than their normal counterparts, but as seen here, this is not always the case. However, what is important is the fact that the saturation cell density for tumor cells is greater than the saturation cell density obtained by normal cells.

Much emphasis has been placed on the interpretation of the large shoulders or curves such as those seen in Figures 3 and 4 for the tumor cell lines with regard to the mechanisms of cell killing,[6] but little attention has been paid to the fact that freshly cultured normal diploid cells fail to show a shoulder. Despite numerous experimental variations in the types of cells used, the method of irradiation, time, dose and age response factors, the results obtained here are highly suggestive that at least for HeLa cells (if not all other tumor cells), the increased shoulder and the increased D_o observed here result in a greatly increased survival when compared to normal human fibroblasts. This increase in survival amounts to about an order of magnitude at 5 gray and two orders of magnitude at 10 gray. It therefore appears that with these large differences, the extrapolation of results from the irradiation of HeLa cells concerning the mechanisms of normal cell killing should be interpreted with great caution.

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EFFECTS OF RADIUM-226 ON BONE FROM A RADIUM DIAL PAINTER AT 12 YEARS AND 55 YEARS AFTER INGESTION

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Samples of bone from two different sites in a female former radium dial painter, collected 43 years apart, were examined with the electron microscope. The results show further evidence for the presence of a fibrotic layer of tissue covering bone mineral which separates the bone lining cells from the source of the radioactive deposits in bone mineral. This work further confirms our contention that many of the cells at risk for the production of bone tumors probably lie outside the single bone lining cell layer which characteristically lies about 1 to 2 μm away from bone mineral in normal control bone.

Introduction

In a very unusual case, bone samples from the same female radium dial painter (03-455) became available following therapeutic surgical procedures at two different times. The samples were obtained from two different sites in the body and were separated by a 43-year time span. This allowed us the rare opportunity to observe radium-related changes as a function of time in the same woman. Her exposure to radium started when she was 16 years old and lasted for a 13-month period in 1922-23 when she painted watch dials with a radium-based compound. Twelve years later (1934), a fibrosarcoma was diagnosed in the head of the left radius, and her left arm was amputated at the shoulder joint. The arm was preserved in formalin and sealed in a museum jar for long-term storage.

In 1975, her estimated body burden of radium-226 was 0.49 μCi, and "moderate changes due to radium, including aseptic necrosis of the left femoral head..." were noted in the radiological summary prepared at that time. Degenerative arthritis added to the complications of radium-related aseptic necrosis and in 1977 the left femoral head and acetabular bone were removed for a total left hip replacement when she was 72 years old. A wedge of trabecular bone was taken from the head of the left femur and preserved in formalin for future histological observation.

Laboratory Procedures

In 1980, slices of bone were cut with a Stryker saw from different sites of the preserved left arm of case 03-455 as illustrated in Figure 1. Smaller

[†]Deceased, February 24, 1982.

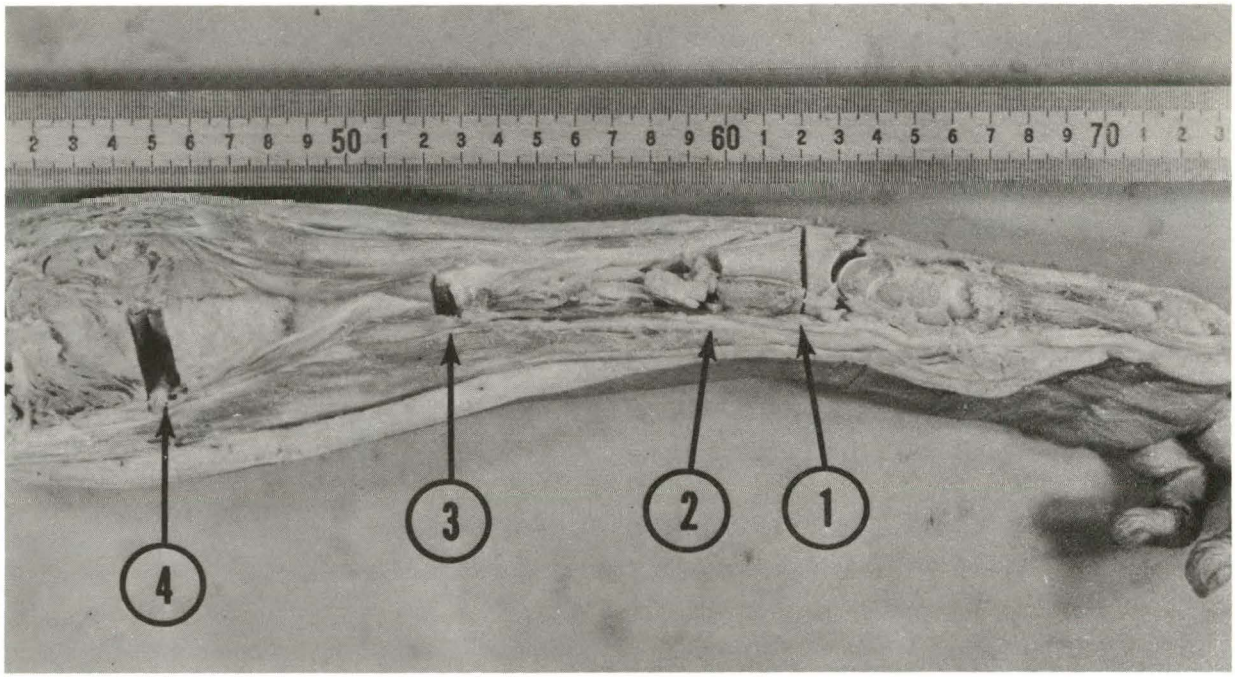

FIG. 1.--Left arm of Radium Case 03-455, showing the sites chosen for electron microscope studies. Site 1, distal end of the radius - trabecular bone; Site 2, distal end of the radius - cortical bone; Site 3, proximal end of the radius - cortical bone adjacent to tumor site; Site 4, center of bone tumor (fibrosarcoma).

samples of bone (1 - 2 mm^3) suitable for electron microscopy were further dissected from the slices indicated in Figure 1. These pieces were taken from the center of the trabecular bone (Slice 1), the endosteal edge of the cortical bone (Slices 2 and 3) and from the center of the tumor (Slice 4). All the samples were processed for electron microscopy by the techniques previously described[1] and examined with the Siemens Type 1A Elmiskop transmission electron microscope.

Results

Site 1 - Distal End of the Radius (Trabecular Bone)

Figure 2 shows a portion of mineralized bone which appears black at the bottom of the picture, covered by a layer of collagen in which three cells with elongated nuclei are clearly visible. The long cytoplasmic process of a reticular cell is seen at the left-hand side, extending into the marrow cavity. The sharply defined white patches are holes in the embedding medium which extend across the marrow spaces where fat has been extracted during the

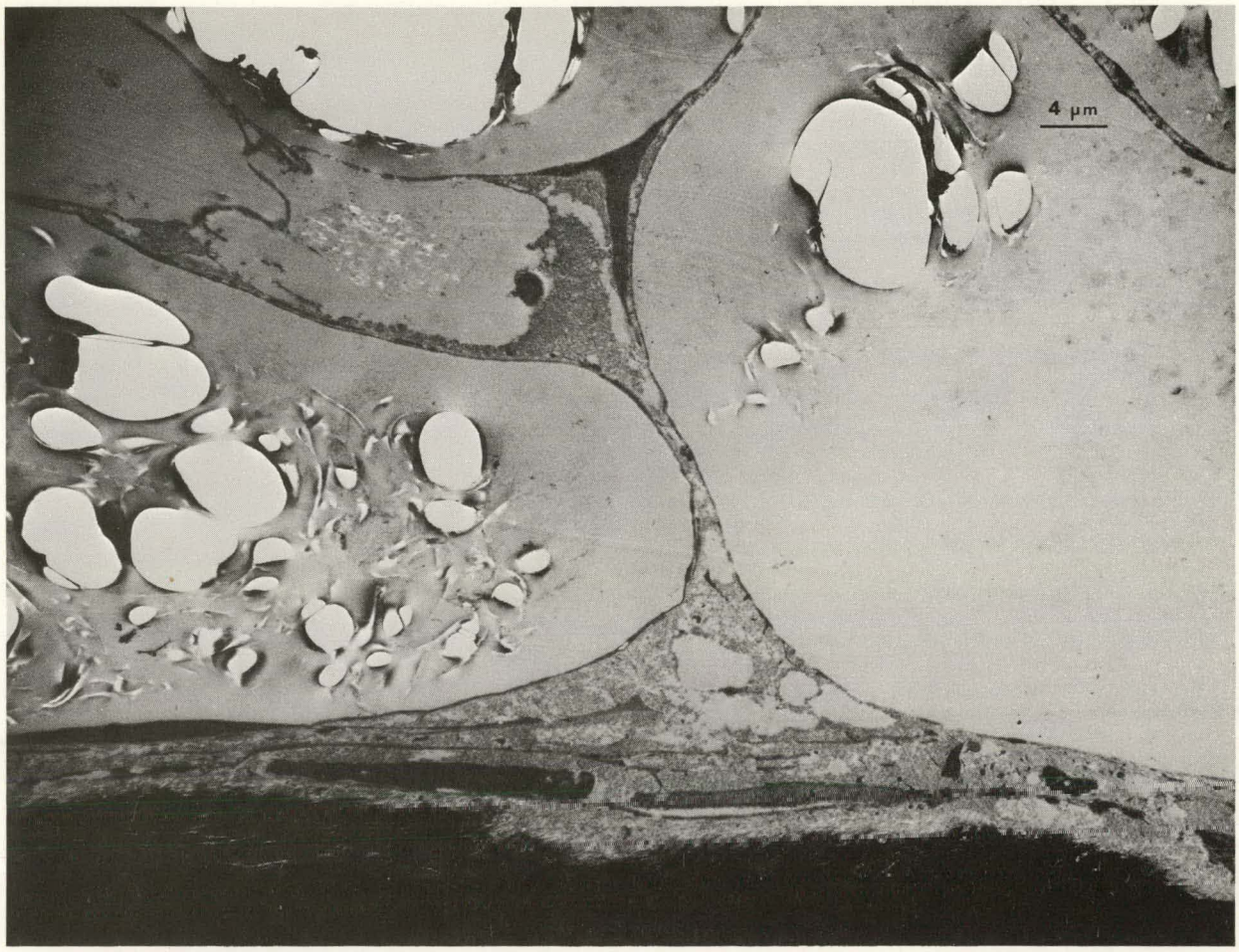

FIG. 2.--Electron micrograph of a portion of trabecular bone from Site 1 indicated in Figure 1.

normal processing procedure. Long cytoplasmic processes form an intercellular network outlining the marrow stroma. This picture, which is typical of the site examined, shows a high cell density with three of the cell nuclei lying within 2 to 3 µm of the bone mineral.

Site 2 - Distal End of the Radius (Cortical Bone)

Figure 3 is a composite picture taken from four adjacent sites along the endosteal surface of the bone. Here we see the cells separated from the bone mineral by a thick layer of collagen through which many cell processes extend to the mineralized surface. The cells have the appearance of being fairly active showing cytoplasmic organelles, together with plump nuclei with the nucleoli sometimes visible.

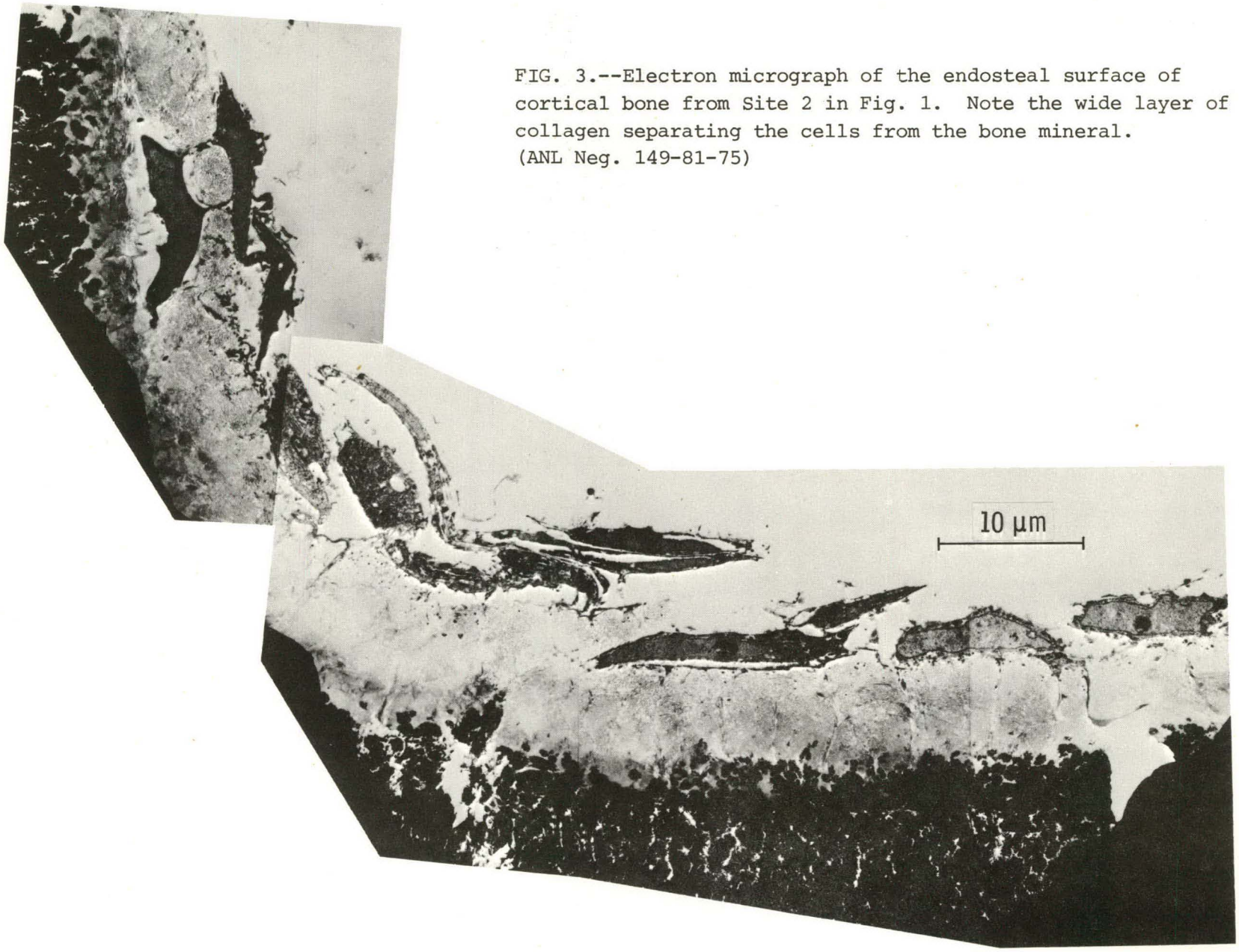

FIG. 3.--Electron micrograph of the endosteal surface of cortical bone from Site 2 in Fig. 1. Note the wide layer of collagen separating the cells from the bone mineral. (ANL Neg. 149-81-75)

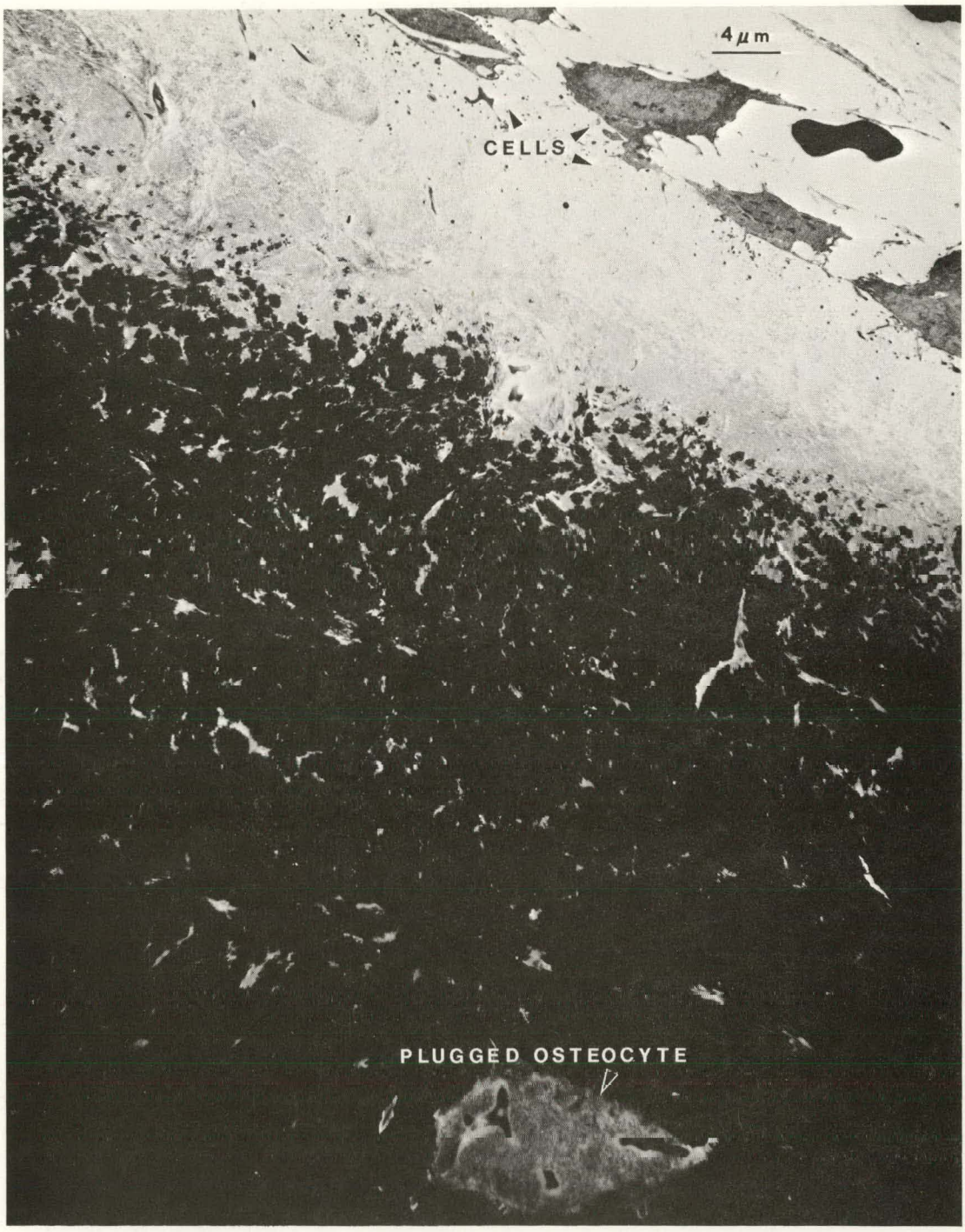

FIG. 4.--Electron micrograph of the endosteal surface of cortical bone from Site 3 in Fig. 1. Note a plugged osteocyte at the middle bottom of the picture.

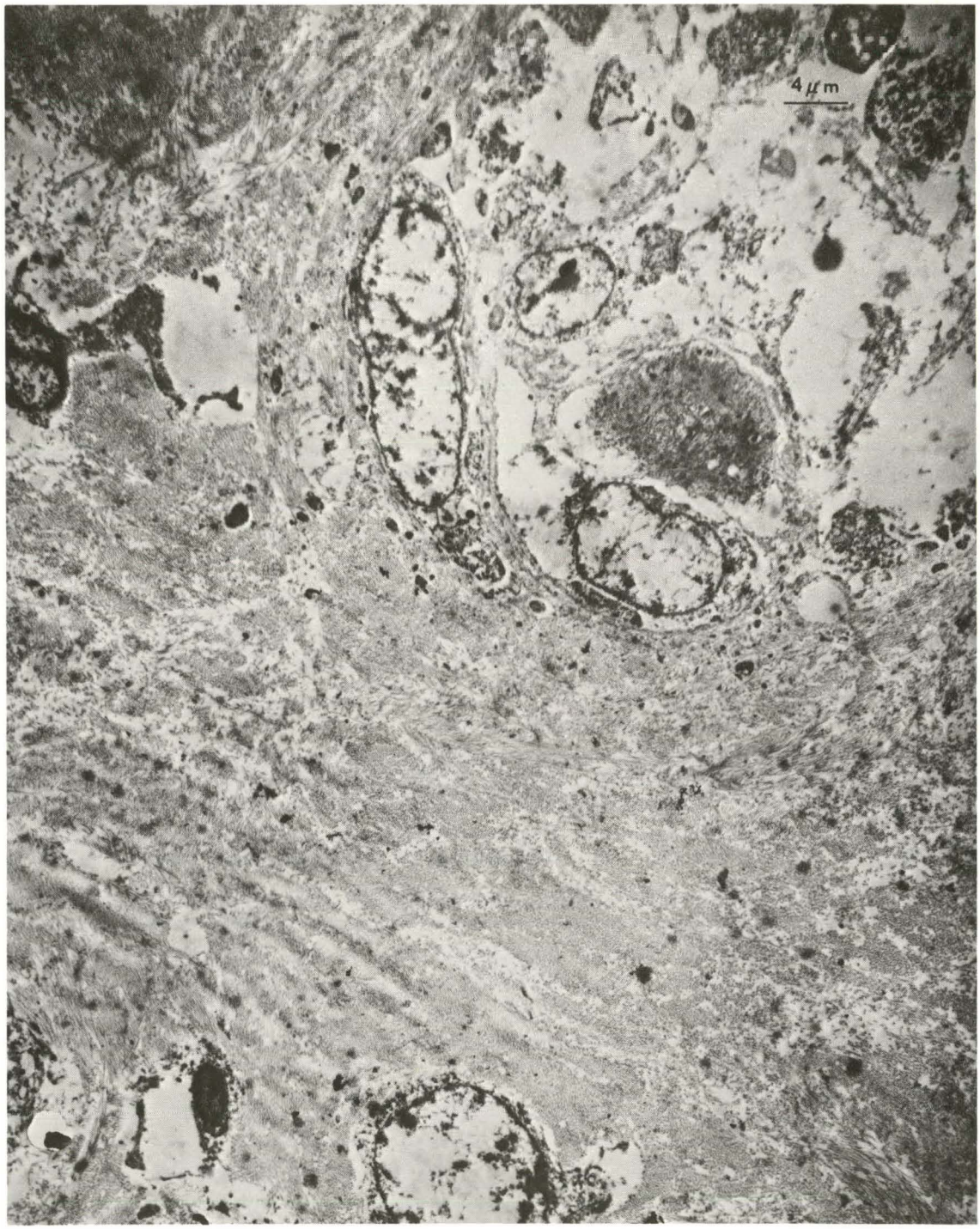

FIG. 5.--Electron micrograph of the center of the tumor, Site 4 in Fig. 1. An island of necrotic cells is seen within a sea of fibrous tissue.

Site 3 - Mid-Cortex Adjacent to Tumor Site (Endosteal Surface)

Figure 4 again shows cells separated from bone mineral by a thick layer of collagen similar to that seen in Figure 3. However, the cells appear to have irregular outlines with an apparent shrinkage of the cells and their processes, suggestive of degenerative changes.

Site 4 - Tumor Tissue (Fibrosarcoma)

Figure 5, taken from the tumor tissue, shows massive areas of collagen with islands of cell remnants showing typical loss of nuclear material and a general loss of organization. No osteoid or bone mineral is observed.

Head of Femur (Trabecular Bone)

Unlike the previous pictures (Figures 1-5) depicting bone from the patient taken at age 28, Figures 6 and 7 represent portions of bone taken from the head of the femur when the patient was 72 years old. Figure 6 shows bone (labelled at the bottom edge) which is partly decalcified with well formed striated collagen matrix. A cell in close contact with this layer (labelled A) has the appearance of an osteocyte with a portion of the nucleus visible and relatively few distinguishable organelles. Beyond this, a layer of collagen separates this cell from the remnants of another cell (labelled B) of unknown origin. Figure 7, taken from a nearby site at the head of the femur, shows more calcified bone (bottom right) than seen in Figure 6. Two cells with similar elongated nuclei are separated from each other and from the bone mineral. The thick layer adjacent to the bone mineral has the usual characteristics of well formed collagen, but the material between the two cells has an amorphous appearance. Canaliculi extending through the collagen layer are apparent here but not as well defined as those seen in Figure 3.

Discussion

The most unusual feature of the bones studied here, when compared with those from control bones (from unexposed individuals), was the greater thickness (~ 5 μm average) of the collagen layer separating the cells from bone mineral. The one exception to this finding was the bone taken from Site 1 - the trabecular bone from the distal end of the radius. This site, which was furthest removed from the tumor, displayed the usual cells lining bone, which were separated from bone mineral by 1 to 2 μm.[1,2]

FIG. 6.--Electron micrograph of the head of the femur when the patient (Case 03-455) was 72 years old. Note the layer of collagen fibrils separating two cells. The bone (bottom right) appears to be partly decalcified.

In the only other bone studied from a radium-exposed individual, a similar wide layer of collagen was found to intervene between the cells and the bone mineral. However, in that case (#05-953), the collagen did not have the regular striations of mature collagen as seen here but rather appeared to be composed of more densely packed fibres with less differentiation.[1]

In the case studied here, numerous cytoplasmic processes were seen extending from the lining cells through the collagen layer to the bone mineral.

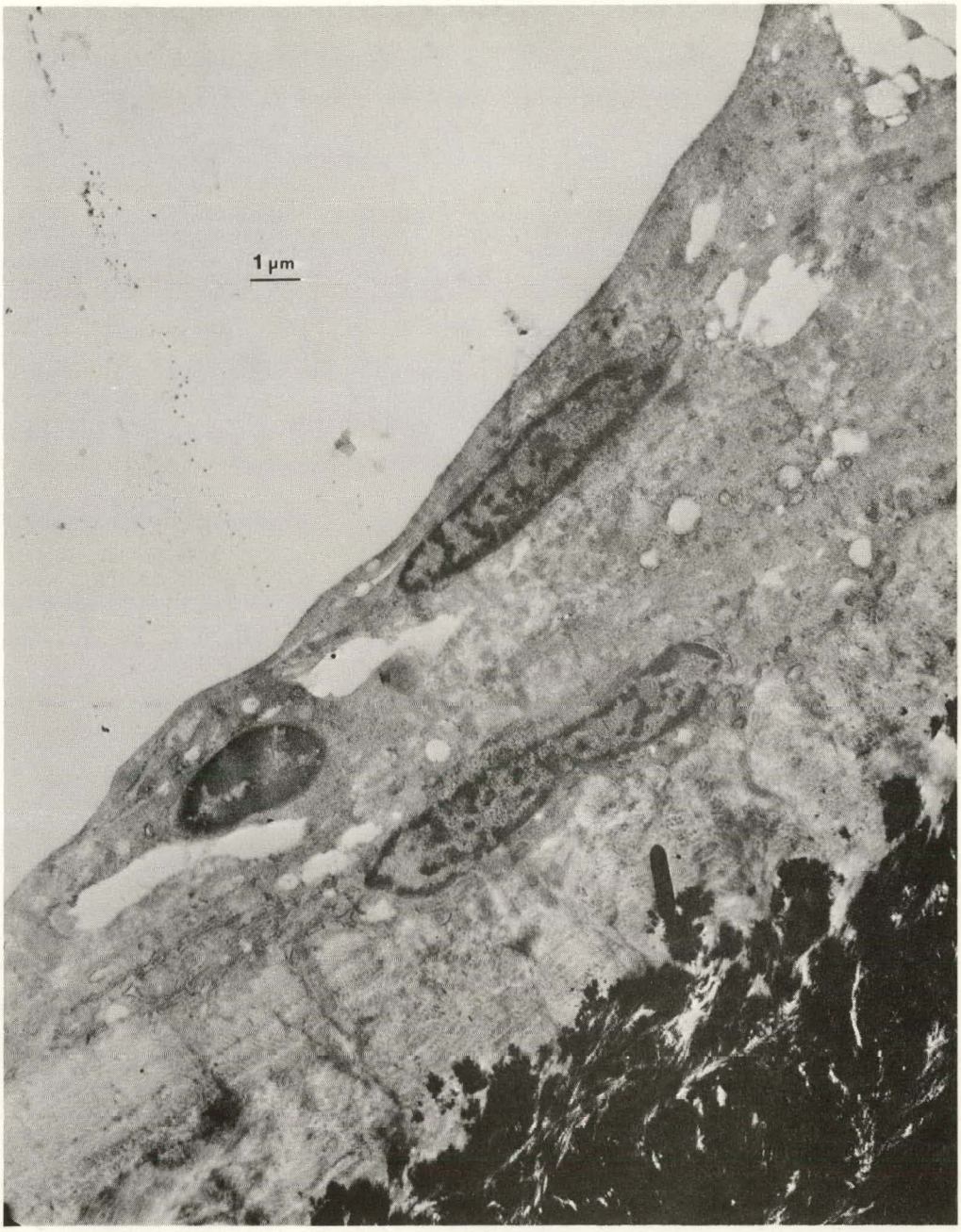

FIG. 7.--An electron micrograph of a site in the head of the femur close to that pictured in Fig. 6. Here two similar cells with elongated nuclei are separated from each other and from bone mineral. Note the thick collagen layer overlying the bone mineral.

These processes were not evident in the cortical bone examined in our previous study of case 05-953. The thick layer of well developed collagen with the cytoplasmic processes which traversed it were more readily distinguishable in the cortical bone taken when the patient was 28. At age 72 when only the head of the femur was available, the trabecular bone showed cellular layers which were widely separated from each other by collagen or other amorphous material. This appearance was in sharp contrast to the trabecular bone from the distal end of the radius at age 28 where the flattened lining cells appear to lie within about one or two cell widths from the mineralized bone. This is characteristic of normal control bone. This suggests that this portion of bone may represent normal new bone growth laid down at a time following her radium exposure (at age 17 or 18) when the level of radium in the blood was greatly reduced. From animal studies,[3] we know that maximum growth takes place at the ends of the long bones, and the mid-cortex of the bone would be expected to retain more of the original deposits of radioactivity at this age, resulting in the abnormal fibrotic layers which we see in the cortex.

Although the material used for the studies on the radius had been preserved in formalin for many years, it appears unlikely that this greatly affected our observations, since examination of the site most remote from the tumor, the distal end of the radius, had the characteristic appearance of the normal control bones which we have previously examined. In addition, similar thick layers of collagen, previously referred to as fibrotic layers, were found in the only other bone from a radium patient examined by electron microscopy.[1] This, therefore, suggests that the fibrotic layer found in the present case is a direct consequence of radiation from the radium deposited in bone mineral. The implications of this finding with regard to the cells at risk for the formation of bone tumors has already been discussed.[4] The work presented here further confirms the necessity to look beyond the 0 to 10 μm layer normally considered relevant by the protection agencies for the calculation of carcinogenic doses.

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IMPROVEMENT OF THE ICRP20 ALKALINE EARTH MODEL*

R. A. Schlenker and A. T. Keane

The ICRP20 model has been adjusted to fit data on the retention of ^{226}Ra in soft tissue and data on the short-term retention of ^{226}Ra in bone. New values of five parameters are given for use in the Ra retention functions. Effective retention integrals have been recalculated using the new parameters. In addition, new estimates have been made of the percentages of the body's natural Ca, Sr, Ba and Ra which reside in soft tissue. A re-analysis of autoradiographic data has also been performed.

Introduction

ICRP Publication 20[1] presents a comprehensive model of alkaline earth metabolism in adults following intravenous injection. The model provides equations for whole body retention, blood retention, plasma activity per gram calcium, soft tissue retention and the retention in various components of bone. The model is based on physiological postulates and its retention functions are expressed in terms of parameters which take on different values for Ca, Sr, Ba and Ra.

Parameter values were determined by fitting the model equations to alkaline earth data. The data were most abundant for Ra and included whole body retention, excretion rate, plasma content, retention by bone long after intake, natural levels and the microscopic distribution of Ra in bone determined autoradiographically.

The majority of the data available on soft tissue retention and data on retention by bone shortly after intake were not utilized in the formulation of the ICRP20 model. Our goal has been to adjust the coefficients and parameters of the ICRP20 model to achieve fits to these data without diminishing the quality of fits to other data on which the model is based. This effort not only has forced close scrutiny of the bone and soft tissue data but also of the analysis of other data in ICRP20.

*Content of a talk with the same title given at the 26th Annual Meeting of the Health Physics Society, June 23, 1981. A fuller exposition of this material can be found in, The Retention of ^{226}Ra in Human Soft Tissue and Bone; Implications for the ICRP20 Alkaline Earth Model, which has been accepted for publication in Health Physics.

The results have been: (1) a new set of parameter values for Ra which provides good fits to all the data including the soft tissue and short-term bone retention data, (2) new values for the effective retention integrals for $^{224,226,228}Ra$ and ^{228}Th to be used in those calculations, and (3) reanalysis of some of the other data with new results and conclusions.

This presentation reports briefly on five topics: (1) the soft tissue and bone data, (2) the changes in parameter values, (3) effective retention integrals, (4) natural alkaline earth levels in soft tissue, and (5) autoradiographic data.

Soft Tissue and Bone Data

The soft tissue data were gleaned from a comprehensive review of the literature since 1915 and also include a few unpublished results from the Center for Human Radiobiology. Patients' exposures were occupational, by injection or through the ingestion of patent medicines containing Ra. The times of observation vary from 5 days to 53 years after intake. Altogether data are available on 87 soft tissue samples from 17 patients, and most are summarized in Figure 1, which compares the fit of the model as published with the improved fit using the new parameter values.

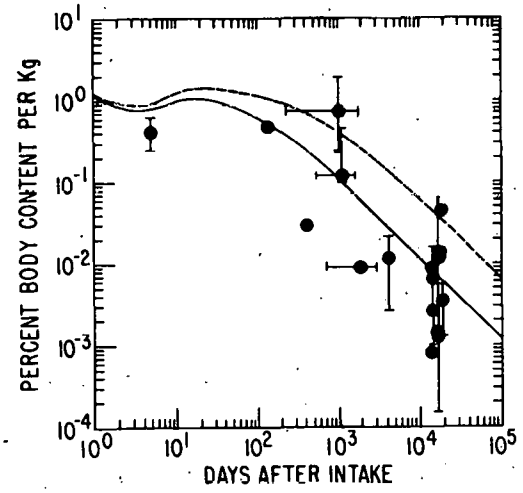

FIG. 1.--Data on the retention of ^{226}Ra in human soft tissue. The abscissa gives the amount of Ra in 1 kg of soft tissue divided by the body burden. The dashed line shows the ICRP20 model as published, the solid line shows the model after parameter adjustment.

The short-term bone data were obtained from measurements on the skeletal remains of 5 persons who had been injected with ^{226}Ra for therapeutic purposes. Times of observation ranged from 8 days to 15 months after

intake. The data are summarized in Figure 2, which shows the fit of the model as published and the improved fit using the new parameter values.

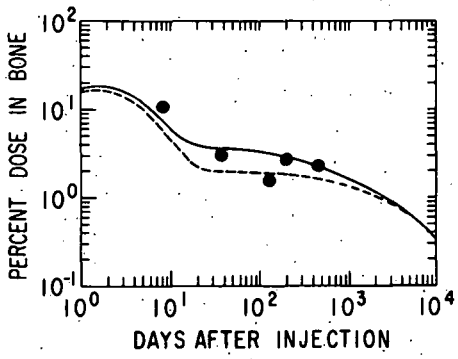

FIG. 2.--Data on the short-term retention of ^{226}Ra in human bone. The abscissa gives the percentage of the injected activity retained by bone. The dashed line shows the ICRP20 model as published, the solid line shows the model after parameter adjustment.

We have examined the fit of the model to the other Ra data and conclude that the model with the new parameter values fits as well as or better than it did with the old ones. With the new values the ICRP20 model fits a broader set of data than it did originally.

Parameter Values

Five parameters were affected by fitting the soft tissue and bone data. These are listed, with their old and new values, in Table 1. The largest

Table 1. Parameter Values

Parameter	Old	New
β	0.608	0.625
ω	1.31	1.44
f_c	3.0	5.63
ν	1.50	1.52
r	0.997	0.99

change occurred in f_c, which nearly doubled in value. (f_c = bone volume activity in all compact bone/bone volume activity in new compact bone.) It must be emphasized that the five parameters shown are functions of one another and were not independently varied. The improvement in fit was actually achieved by changing a function which is directly proportional to some of these parameters and inversely proportional to others. Specifically, the model was adjusted by doubling the coefficient of 1-R in the expression for Θ, a quantity upon which the retentions in bone volume and soft tissue are dependent ($\Theta = [f_c\ 0.8\ c\lambda\omega(1-R_{BODY})/p\varepsilon^b\ \beta\eta k]^{-1/b}$).

Effective Retention Integrals

The absorbed dose accumulated during a time, t, is proportional to the integral of the effective retention function over time t. We have calculated effective retention integrals for $^{224,226,228}Ra$ and for ^{228}Th for 1 year, 50 years, and infinite time periods. For all nuclides and all periods of integration the change in parameters brought about a reduction in the integral

Table 2. Fifty Year Retention Integrals for ^{226}Ra

	Old, days	New, days
Soft tissue	21.2	9.0
Bone volume	95.6	109

for soft tissue and an increase in the integral for bone volume. As an example, 50-year integrals are given in Table 2 for ^{226}Ra. The soft tissue value drops by more than a factor of 2 and the value for bone volume increases by 15%.

Natural Alkaline Earth Levels in Soft Tissue

In ICRP20 estimation of the amount of an alkaline earth element naturally present in soft tissue was based on sample means. However, trace element concentrations in a given organ or tissue are asymmetrically distributed in the population and medians are more appropriate than means for characterizing the data.[2] Using sample medians,[3] we have calculated the percentages of the body's natural Ca, Sr, Ba, and Ra present in soft tissue. These values and those used in ICRP20 are presented in Table 3. The differences between them may have a significant impact on the model since it was formulated to assure agreement with estimates of soft tissue percentages based on observation.

Using the new parameter values for ^{226}Ra, the model agrees with the new soft tissue percentage but not with the old value. This lends credence to our supposition that medians rather than means are the proper quantities for determining the amount of an alkaline earth occurring naturally in soft tissue.

Table 3. Natural alkaline earth contents of soft tissue as percentages of total body content.

Element	Current empirical estimate[b]	ICRP Publication 20 estimates[a]	
		Empirical	Predicted
Ca	0.28	0.4	0.403
Sr	0.98	2	1.98
Ba	4.7	--	6.36
^{226}Ra	5.5	10-30	14.4

[a]Close agreement between empirical and predicted values is achieved in ICRP Publication 20 by adjustment of model parameters, in particular f_C.

[b]Based on the soft tissue masses quoted in Reference Man, minus the blood contents of the tissues.

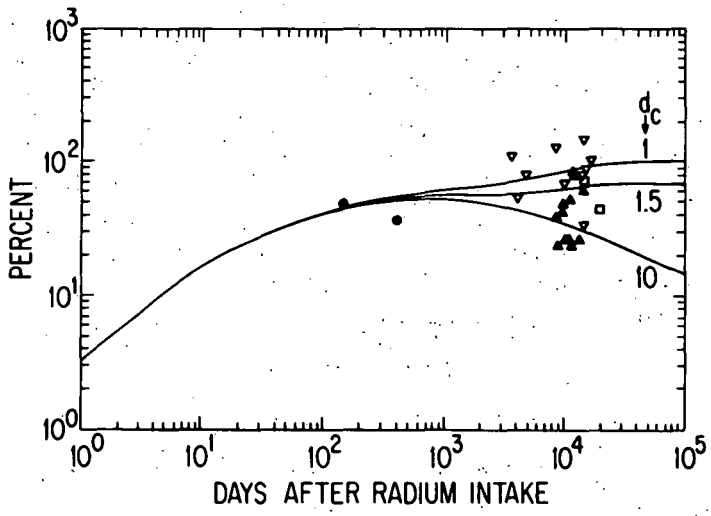

FIG. 3.--Autoradiographic data. The abscissa is the ratio of diffuse specific activity to uniform specific activity multiplied by 100%. Curves based on the original model (d_C = 1) and on the modified model with two values of d_C are shown. At times less than about 100 days, the three curves coincide. The best fit occurs with d_C = 1.5. The different symbols refer to the results of different workers.

Autoradiographic Data

In ICRP20 the model was compared with data on the microscopic distribution of ^{226}Ra in bone, determined by autoradiography. A poor fit was obtained. As a result, the authors modified the model by introducing a new concept: that the rate of Ra loss from hot spots is less than the rate of loss from the diffuse component. This required the definition of a new parameter, d_C. Large values of d_C indicate large differences in the loss rate, values near 1 indicate small differences, and where d_C = 1, there is no difference.

In ICRP20, the best fit to the data was obtained with $d_c = 10$. The analysis was based on the assumption that areas of bone remodeled after Ra intake could be distinguished in alpha track autoradiographs from unremodeled areas. Actually, such a distinction is impossible when the track density is sufficiently low to permit track counting. Removal of this assumption and use of the new parameter values results in the comparison between model and data shown in Figure 3. The best fit is now obtained with $d_c = 1.5$. Although the modified model still provides a better fit to the data than the original model a much smaller difference in Ra loss rates is necessary.

Summary

The ICRP20 model has been improved by adjusting it to fit a broader spectrum of Ra data than used in ICRP Publication 20, and by reconsidering other aspects of the model including the estimates of the natural alkaline earth content of soft tissue and the analysis of autoradiographic data.

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FERTILITY OF WOMEN AFTER EXPOSURE TO INTERNAL AND EXTERNAL RADIATION

Anthony P. Polednak[†]

Fertility was examined in 199 women exposed to internal and external radiation while employed in the radium watch-dial painting industry in Illinois between 1916 and 1929. In women with at least one live birth, mean log live-birth rate was significantly lower in the highest (estimated) ovarian-dose group (i.e., > 20 rem) than in the lowest group (< 5 rem). In multiple regression analysis, intake dose (proportional to alpha-particle dose to ovaries) but not duration of employment (relevant to external gamma-ray dose to ovaries) was a statistically significant predictor of log live-birth rate. There was no evidence for an increase in fetal deaths with increasing ovarian dose level (rem). This suggests that the findings on live-birth rate may not involve post-implantation dominant lethal mutations, but pre-implantation losses could not be evaluated. Some possible explanations for these findings are discussed.

*Abstract of a paper published in J. Environ. Path. Toxicol. 4, 457-470 (1980).

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BREAST CANCER IN FEMALE RADIUM DIAL WORKERS FIRST EMPLOYED BEFORE 1930*

E. E. Adams and A. M. Brues

Female radium dial workers first employed before 1930 were analyzed for breast cancer mortality and incidence using method and rate tables described by Manson and the Mantel-Haenszel summary chi-square test for significance. Of 1180 located women, 736 were measured to estimate radium intake. This measured group was analyzed for breast cancer mortality and incidence according to four possible risk factors: radium intake dose, duration of employment, age at first exposure, and parity. The located women had a mortality ratio of 1.51 ($p < 0.05$). The measured women showed a significant excess of breast cancer incidence and mortality only among those women with a radium intake of 50 μCi or greater. Although not significant, incidence and mortality ratios were slightly higher for nulliparous women.

*Abstract of paper published in J. Occup. Med. 22, 583-587 (1980).

LATE EXCRETION RATES OF ^{226}Ra AND ^{210}Pb FOLLOWING OCCUPATIONAL OR IATROGENIC EXPOSURE. I. ^{226}Ra

R. B. Holtzman, J. Y. Sha and F. Markun

The urinary and fecal excretion rates of ^{226}Ra have been determined for 53 subjects who had been exposed to ^{226}Ra; 25 had been radium dial painters, 16 were iatrogenic (medical) cases and 12 were former radium chemists. The mean coefficient of elimination, CE (fraction of body content excreted annually), was significantly lower for the medical cases than for dial painters. The values of the total CE's (±S.E.) were 2.23 ± 0.39, 0.98 ± 0.10, and 1.30 ± 0.23% per yr, for the dial painters, medical cases and chemists, respectively. These values correspond to instantaneous values of 0.92, 0.41 and 0.34 for the exponent b in the power function retention equation, $R = At^{-b}$. The first of these values differs significantly from the Norris value of 0.52. The mean ratio of urinary-to-fecal excretion rates was 3.0 ± 0.7% (±S.E.).

Introduction

Knowledge of the excretion rates of ^{226}Ra and its longer lived decay products, ^{210}Pb (22 yr) and ^{210}Po (138 d), from persons with significant amounts of these nuclides, is needed for the evaluation of long-term radiation doses in persons containing ^{226}Ra. These data are also useful in estimating the parameters of the nuclide retention functions used in estimation of body content of such persons.

In previous studies values have been reported for excretion rates of ^{226}Ra from persons with long-standing burdens (20 or more years) by: Norris et al. for 19 Elgin patients,[1] Muth and Oberhausen for one radium industry worker[2] (and 12 with exposures just prior to measurement), and Lucas et al. for four former radium dial painters.[3] The latter group also reported values for blood and serum clearance rates. More recently Wenger and Cosandey reported measurements made over a period of 10 yr of ^{226}Ra and ^{90}Sr excretion rates for a dial painter and her husband.[4]

To obtain a more complete picture of the metabolic parameters, we have determined the excretion rates of ^{226}Ra for 53 subjects with long-term ^{226}Ra body burdens, and we report the results here. Each subject studied had a body content of more than 10 nCi of ^{226}Ra at the time of collection of the excreta.

Experimental Material

Data relating to the subjects are tabulated in order of Center for Human Radiobiology (CHR) case number for 25 former radium dial painters in Table 1,

for 16 subjects exposed to radium for medical purposes (iatrogenic exposures) in Table 2, and for 12 radium chemists in Table 3. For the dial painters (Table 1) exposed to radium before 1926, the "duration of exposure" was limited to those exposures received prior to that year, because after that time radium intake was greatly reduced by improved hygiene when "brush tipping" was stopped. Other data on these subjects may be found in Ref. 5.

The subjects in this study were generally cooperative. Most of the specimens of urine and feces were collected in metabolic wards, mainly at the MIT Clinical Research Center.* Cases 03-115, 03-116, 03-125, 03-135 and 03-139 were residents of Elgin State Hospital, Elgin, Illinois, and specimens were collected for two weeks while they were in the metabolic ward at Manteno State Hospital, Manteno, Illinois. Some of the other subjects collected the specimens on their own at home for one or more days. These subjects appeared to be reliable and the collections seemed to be complete. The body burden data were taken from Ref. 5 when the year of measurement coincided with that of sample collection. Some data were those of Miller et al.,[6] and some were taken from the list of whole body gamma-ray and radon-in-breath measurements in the CHR files.[7]

Some of the values of body content are estimates from data in the latter files, obtained by interpolation of measurements made over the years as noted in the tables. The whole body content was usually based on the measured ^{214}Bi (RaC) value, which, in the Miller measurements,[6] was assumed to represent 31% and, in the CHR measurements, 37% of the ^{226}Ra content.[7] The body-burden values from the two groups (Miller and CHR) are reasonably comparable and are consistent with the evidence that the retention of radon in man increases with time, as it does in animals.[1,8]

Experimental Methods

Most of the samples were wet-ashed in nitric and perchloric acids. The nitrates were removed and the solutions converted to hydrochloric acid solutions for the ^{210}Pb determinations.[9] Some of the earlier samples (with 01-prefixes) had been ashed at 500°C at the MIT Radioactivity Center and

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*Massachusetts Institute of Technology (MIT) Clinical Research Center, Cambridge, Mass.

Table 1. Exposure data for radium dial painters (female)[a]

Case No.	Duration of exposure,[b] wk	Year of first exposure	Approximate age at mid-exposure, yr	Year of collection	Age at collection,[c] yr	Time since mid-exposure,[c] yr	Body content of ^{226}Ra,[c,d] nCi (yr of measurement)
01-063	213	1927	18	1976	66	47	34
01-073	122	1921	22	1966	66	44	87
01-084	156	1923	21	1966	62	36	49
01-252	104	1917	20	1968 1972	74 76 } 75	54 56 } 55	31[e] 29[e] } 30
01-268	48	1920	20	1967	66	46	100
01-348	19	1924	22	1966	64	42	112
01-349	10	1924	17	1966	59	42	93
03-401	95	1923	24	1962	62	38	2200[e]
03-402	156	1923	20	1964 1966	59 61 } 60	38 41 } 40	1150[f] 1100[f] } 1125
03-405	104	1924	21	1962	58	35	625
03-417	60	1924	16	1962 1966	53 57 } 55	37 41 } 39	700[e] 590[e] } 645
03-423	156	1923	18	1962	55	33	591
03-431	156	1922	23	1962	61	38	1297 (1963)
03-459	43	1924	19	1962	56	37	980[e]
03-488	26	1922	15	1973	66	51	67 (1975)[g]
03-727	156	1923	19	1972	66	40	165
05-014	208	1916	18	1962 1972	62 72 } 67	50 60 } 55	140 (1968)[e] 120 (1973)[e] } 130

Table 1 (cont.). Exposure data for radium dial painters.

Case No.	Duration of exposure,[b] wk	Year of first exposure	Approximate age at mid-exposure, yr	Year of collection	Age at collection,[c] yr	Time since mid-exposure,[c] yr	Body content of ^{226}Ra,[c,d] nCi (yr of measurement)
05-025	78	1917	25	1962	69	44	94 (1967)[e]
				1969	76 } 74	51 } 50	89[e] } 90
				1971	78	53	86[e]
05-040	54	1917	19	1967	68	49	11
05-215	52	1920	35	1962	76	41	1700[e]
05-281	148	1916	19	1962	64	45	660 (1963)
05-284	156	1919	21	1962	63	41	290[e]
				1963	64 } 67	42 } 45	280[e] } 254
				1967	68	46	230[e]
				1969	70	48	218[e]
05-413	39	1916	17	1967	67	50	18 (1969)
09-028	78	1916	20	1972	75 } 76	55 } 56	72 } 76
				1975	78	58	60
09-032	52	1917	16	1967	65	49	100

[a] Data from Ref. 5 except as noted.

[b] If the exposure started prior to 1926 the exposure was assumed to have ended Dec. 31, 1925 when brush tipping ceased, i.e., most of the exposure is assumed to have occurred during the period when the brushes were tipped.

[c] Only average value of multiple data on a given subject used in calculating mean values.

[d] Year of measurement is given only if it differs from the year of collection shown in column 5.

[e] Estimated from data in CHR files, (Ref. 7).

[f] Ref. 15.

[g] J. Rundo, personal communication.

Table 2. Exposure data for medical (Iatrogenic) radium cases [a]

Case No.	Sex	Expos. type,[b] year of first exposure	Age at mid-exposure, yr	Duration of exposure, wk	Year of collection	Age at collection,[c] yr	Time since intake,[c] yr	Body content, of ^{226}Ra,[c] nCi (at yr of collection)
01-017	F	RD26	45	156	1969	86	41	1300[d]
					1971	88 } 89	44 } 45	1270[d] } 1230
					1977	94	50	1120[d]
01-144	F	RW22	25	26	1968	71 } 72	46 } 48	762[d] } 728
					1971	74	49	694
01-157	F	RD25	29	13	1969	75	44	49
01-184	M	RI22	35	10	1968	81	46	48[d]
01-196	M	RD30	23	20	1970	63 } 64	40 } 41	68 } 68
					1972	65	42	69
01-431	F	RI22	23	52	1966	65	43	880[d]
01-520	F	RD30	48	+0[e]	1967	85	37	670
01-558	M	RD27	16	130	1973	60	44	362
03-115	F	RI31	21	26	1970	59	38	730[d]
03-116	F	RI31	24	25	1970	63	38	1450[d]
03-125	F	RI31	17	11	1970	57	39	650[d]
03-135	M	RI31	26	+0[e]	1970	65	38	1020[d]
03-139	M	RI33	25	11	1970	62	36	390[d]
03-206	M	RI36	22	4	1973	59	37	3300
10-010	F	RI30	35	+0[e]	1972	77	42	8600
10-825	M	RI27	23	0(1)	1976	72 } 72	49 } 50	1150[d] } 1100
					1977	73	50	1070[d]

[a] Data from Ref. 5 except as noted.
[b] The first two characters are the type of exposure, RD Radithor water, RW radium water and RI radium injection. The two digits are the year of exposure in the 1900's.
[c] Only the average values of multiple data on a given subject were used in calculating the overall mean.
[d] Estimate from data in CHR files, (see text) (Ref. 7).
[e] +0: exposure duration unknown, not used in calculation of mean duration of exposure.

Table 3. Exposure data for radium chemists [a]

Case No.	Sex	Duration of exposure, wk	Year of first exposure	Age at mid-exposure, yr	Year of collection	Age at collection, [b] yr	Time since uptake, yr	Body content [b,c] of ^{226}Ra, nCi
01-177	M	312	1936	24	1969	54	30	61
01-205	M	52	195-	30	1971	50	20	15
01-208	M	1144	1939	49	1967	66	17	900
					1969	68 } 68	19	850 } 850
					1971	70	21	818
01-330	M	364	1942	31	1976	61	30	66
01-356	M	572	1937	31	1969	57	26	23
01-408	F	416	1934	20	1966	48	28	20 [d]
01-410	F	156	1940	22	1966	46	24	51 [d]
01-521	M	520	1942	37	1967, 1972	60	23	24 [e]
01-522	M	240	1928	42	1969	64	22	240
01-530	M	104	1943	24	1968	48	24	52
05-127	M	999	1918	35	1967	74	39	20
05-383	F	165	1917	18	1973	72	55	73

[a] Data from Ref. 5 except as noted.

[b] Only the average value of multiple data on a given subject were used in calculating the overall mean values.

[c] The year of measurement is given only if it differs from the year of collection in column 6.

[d] CHR files, Ref. 7.

[e] Estimate from data in CHR file VVRA, Ref. 7.

dissolved in nitric acid. These were later converted to hydrochloric acid solutions in our laboratory.

^{226}Ra was determined by the radon emanation method of Lucas.[9,10]

The precision of an individual measurement is estimated to be about ±2% (repeated emanations on a given processed sample). However, when account is taken of the uncertainties of the collection process (namely, in determination of the completeness of collection and the accuracy of the time periods) and of the uncertainties of the analytical procedures (such as loss or contamination during dissolution and oxidation of the specimens and in the aliquoting of the solutions) the overall relative standard error of a single measurement is estimated to be about 10%.

Results and Discussion

The exposure data for the three groups are summarized in Table 4. Where little difference was noted between the arithmetic and geometric mean values and the geometric standard deviation was small (< 1.4), the arithmetic means are given. For the parameters, ^{226}Ra body content and duration of exposure, which have wide ranges of values, the geometric means and geometric standard errors ($\overset{\times}{\div} SE_g$) are given instead of the arithmetic ones. Based on the parameters shown, the only feature that the three groups have in common is the age at collection, 60 to 69 yr. The chemists and the medical cases were exposed at similar ages; they were about ten years older at exposure than the dial painters. The three female chemists were substantially younger than the males. The time between intake of the radium and collection of the excreta for the chemists was 12 to 13 yr less than that for the others, but the effect of this is offset by the longer duration of exposure of the chemists, viz. the geometric means ($\overset{\times}{\div} SE_g$) were about 7 yr (1.4) versus 1.5 yr (1.2) for the dial painters, and less than 1 yr for the medical cases.

The mean body content of ^{226}Ra in the chemists was lower than in the other groups. For the medical cases the mean body content of the males was somewhat lower than that of the females, but the difference was not statistically significant ($P > 0.05$).

The excretion rates of ^{226}Ra for the subjects grouped as above are presented in Tables 5, 6 and 7, but the subjects within each group are listed in order of increasing body content of ^{226}Ra. The years of collection,

Table 4. Summary of exposure data, (Mean ± S.E.)

Group	Subgroup, No., Sex	^{226}Ra body content (SE_g),[a] (Range), nCi	Year of first exposure	Age at exposure, yr	Time since intake, yr	Duration of exposure (SE_g),[a,b] wk	Age at collection, yr
Radium dial painters	25 F	178 (1.4) (11-2200)	1921.0 ± 0.7	20.2 ± 0.8	44.1 ± 1.3	79 (1.2)	65 ± 1
Medical cases	7 M	402 (1.8) (48-3300)	1929.4 ± 1.7	24 ± 2	42 ± 2	10 (1.9)	66 ± 3
	9 F	812 (1.6) (49-8600)	1927.6 ± 1.3	29 ± 4	43 ± 1	30 (1.3)	71 ± 4
	M + F	600 (1.4) (48-8600)	1928.4 ± 1.0	27 ± 2	42 ± 1	15 (1.6)	69 ± 3
Radium chemists	9 M	58 (1.6) (20-850)	1937.3 ± 3.2	34 ± 3	25 ± 2	420 (1.5)	61 ± 2
	3 F	42 (1.5) (20-73)	1930 ± 7	20 ± 1	36 ± 10	220 (1.4)	55 ± 8
	M + F	53 (1.4)	1935.6 ± 2.9	30 ± 3	27 ± 3	360 (1.4)	60 ± 3

[a] Geometric mean and geometric standard error (SE_g) used for these quantities because of the wide distribution of values. For the other quantities the differences between the arithmetic and geometric means are not significant.

[b] Does not include three medical cases with exposures of unknown duration.

ranging from 1962 to 1976, are shown and, where sufficient data were obtained in a given collection period, the results are presented separately to make possible estimates of the variability of excretion rates with time.

The results presented are essentially all those available to us in the three groups of exposure classification for subjects with body contents greater than 10 nCi. Two cases were excluded: one (01-507) because her excretion patterns observed at different periods over several years indicated ^{226}Ra exposure just prior to collection, and another (01-576), a Swiss dial painter, because her exposure pattern differed significantly from those of the American dial painters. Her ^{226}Ra retention and excretion patterns have been characterized elsewhere.[4]

The values presented were corrected for environmental levels with the assumptions that the normal ^{226}Ra fecal and urinary excretion rates were 1.0 ± 0.5 and 0.010 ± 0.010 pCi/day, respectively. However, for eight dial painters who resided in or near Ottawa, Illinois, where the municipal water supplies contain high levels of ^{226}Ra (~ 6 pCi/L),[11] the dietary levels, and hence the elimination rates, are assumed to be five times those for the other subjects, namely 5 ± 2 pCi/day in feces and 0.05 ± 0.05 pCi/day in urine. The value for the "normal" fecal excretion rate is equal to the intake rate. The "standard" daily U.S. diet contains about 1.4 pCi ^{226}Ra/day,[12] but our study group consists of older persons, mostly women, who might be expected to consume less than average amounts of food. Moreover the standard is based on total food consumption in various cities and includes food not necessarily consumed. While a group of dietary values from some of the cases reported here averaged 1.9 pCi/day (five women) and 2.4 pCi/day (six men),[12] these values appear to be atypical of the dietary levels. For the five subjects maintained on the metabolic ward at Manteno State Hospital the mean intake was 1.07 pCi/day from measurements on daily diets taken over a 14-day period.

Furthermore, the data in Tables 5 to 7 may be used to justify the validity of the above assumptions of normal excretion rates. Fits of straight-line regression equations to the excretion rate data (corrected for the above estimates of environmental levels) versus ^{226}Ra body content show that at natural levels of ^{226}Ra body content (^{226}Ra ~ 50 pCi), the urinary excretion rates are significantly greater than zero ($P < 0.05$) for the dial painters and medical cases, as are the fecal rates for the latter group. However, if the calculations are limited to data from those cases with body

Table 5. ^{226}Ra elimination rates and coefficients of elimination for dial painters (all females)

Case No.	^{226}Ra body content, nCi	Year of collection	Sample size, day		Excretion rates, pCi/day ±S.E.[a] (corrected for natural levels)			Coefficients of elimination, % ^{226}Ra content/yr			
			Urine	Feces	Urine	Feces	Total[b]	Urine	Feces	Total[b]	
05-040	1[illegible]	1967	2.87	1.0	0.13 ±0.024	1.18±0.70	1.30	0.43 ±0.09	3.9 ±2.4	4.3	
05-413	18	1967	2.0	1.0	-0.009±0.01	-0.17±0.53	-0.18	-	-	-	
01-252	31	1968	0.91	-	0.24 ±0.06	-	-	0.29 ±0.08	-	-	
	29	1972	5.38	1.85	0.022±0.010 (±0.003)	6.6 ±1.4	6.7	0.028±0.014	8.3 ±2.0	8.3	
01-063	46	1972	3.45	-	0.48 ±0.07 (±0.03)	-	-	0.36 ±0.06	-	-	
	34	1976	8.31	9.0	0.25 ±0.03 (±0.02)	2.8 ±0.7 (±0.38)	3.12	0.27 ±0.04	3.0 ±0.8	3.4	
01-084	49	1966	4.0	-	0.095±0.018	-	-	0.071±0.015	-	-	
09-028	72	1972	2.96	4.23	0.034±0.012 (±0.018)	0.58±0.55 (±0.77)	0 61	0.017±0.006	0.29±0.27	0.9	0.31
	60	1975	9.51	9.91	0.11 ±0.017 (±0.026)	2.49±0.65 (±0.58)	2 60	0.069±0.013	1.5 ±0.4		1.6
03-488[c]	67	1975	1.0	-	0.10 ±0.06	-	-	0.049±0.030	-	-	
01-073	87	1967	3.0	3.0	1.07 ±0.17	7.4 ±1.4	8.5	0.45 ±0.08	3.10±0.66	3.56	
01-349	93	1966	3.0	-	0.12 ±0.01	-	-	0.047±0.010	-	-	
05-025	120	1962	12	12	0.16 ±0.02 (±0.04)	6.2 ±1.0 (±1.0)	6.4	0.049±0.008	1.89±0.35	1.95	
	94	1967	1	2	0.25 ±0.06	0.9 ±0.6	1.16	0.097±0.025	0.35±0.23		0.45
	89	1969	1	-	0.18 ±0.04	-	-	0.074±0.019	-	0.22	-
	85	1971	1.68	1	0.19 ±0.04 (±0.03)	0.25±0.6	0.44	0.082±0.018	0.11±0.3		0.19

[a] The values of the standard errors derived from multiple measurements are given in parentheses.

[b] The values of the errors for total elimination are essentially identical to those for the corresponding fecal values.

[c] These subjects resided in an area with high ^{226}Ra content in the drinking water [Ottawa (6 pCi/L), Marseilles, Illinois, (>6 pCi/L)] (Ref. 11), so that the normal ^{226}Ra fecal and urinary excretion rates were assumed to be 5±1 and 0.05±0.05 pCi/day, respectively.

Table 5 (cont.). ^{226}Ra elimination rates and coefficients of elimination for dial painters (all females)

Case No.	^{226}Ra body content, nCi	Year of collection	Sample size, day		Excretion rates, pCi/day ±S.E.[a] (corrected for natural levels)			Coefficients of elimination, % ^{226}Ra content/yr		
			Urine	Feces	Urine	Feces	Total[b]	Urine	Feces	Total[b]
09-032	100	1967	2.0	-	0.088±0.019	-	-	0.032±0.008	-	-
01-348	112	1966	2.9	1.0	0.18 ±0.02	2.1 ±0.8	2.3	0.059±0.009	0.67±0.28	0.73
01-268	130	1967	5.3	14	0.12 ±0.02 (±0.012)	6.5 ±1.0 (±1.5)	6.6	0.034±0.007	1.8 ±0.3	1.8
05-014	140	1967-1970	7.0	3.0	0.52 ±0.05 (±0.16)	2.0 ±0.7	2.5	0.14 ±0.02	0.52±0.2	0.66
	120	1972	3.78	6.06	0.15 ±0.02 (±0.05)	8.3 ±1.3 (±2.6)	8.5	0.046±0.007	2.51±0.5	1.5 2.6
03-727	165	1972	15.0	8.7	0.020±0.11 (±0.004)	3.33±0.72 (±0.55)	3.35	0.004±0.002	0.74±0.18	0.75
05-284	290	1962	12	7.0	0.90 ±0.11 (±0.02)	47.3 ±6.1 (±7.1)	48.2	0.11 ±0.02	5.96±0.97	6.07
	280	1963	-	3.0	-	31.4 ±5.0	-	-	4.09±0.77	-
	230	1967	-	1.0	-	44 ±10	-	-	6.98±1.7	-
	218	1969	5.7	8.0	0.61 ±0.08	33.8±4.3 (±6.2)	34.4	0.10 ±0.02	5.66±0.91 5.67±0.59 (Mean)[d]	5.76
03-423[c]	591	1962	2.0	4.0	0.57 ±0.12 (±0.28)	37.0±6.3	37.6	0.035±0.008	2.29±0.45	2.32
03-405[c]	625	1962	3.2	5.0	0.41 ±0.09 (±0.10)	11.4±3.0	11.8	0.023±0.005	0.67±0.17	0.69
05-281	660	1962	9.0	4.0	0.48 ±0.06 (±0.09)	36.1±5.3 (±7.5)	36.6	0.027±0.004	2.00±0.35	2.03
03-417[c]	700	1962	3.0	5.0	0.68 ±0.12 (±0.08)	40.9±6.5 (±7.2)	41.7	0.035±0.007	2.13±0.40	2.1
	590	1966	11.0	12.0	0.42 ±0.07 (±0.07)	24.8 ±4.0 (±2.8)	25.2	0.026±0.005	1.53±0.19	1.0

Table 5 (cont.). ^{226}Ra elimination rates and coefficients of elimination for dial painters (all females)

Case No.	^{226}Ra body content, nCi	Year of collection	Sample size, day		Excretion rates, pCi/day ±S.E.[a] (corrected for natural levels)			Coefficients of elimination, % ^{226}Ra content/yr		
			Urine	Feces	Urine	Feces	Total[b]	Urine	Feces	Total[b]
03-459[c]	980	1962	3.0	5.0	1.98±0.31 (±0.34)	80 ±12 (±3.9)	82.3	0.074±0.014	2.98±0.52	3.0
03-402[c]	1150	1964	-	3	-	293 ±46[e] (±80)	-	-	9.3 ±1.7[d]	-
	1100	1966	7.0	7.11	0.74±0.11 (±0.11)	50.0±7.1 (±6.0)	50.7	0.025±0.004	1.66±0.29	1.68
03-431[c]	1297	1963	2	-	0.53±0.11 (±0.08)	-	-	0.015±0.004	-	-
05-215	1700	1962	3	6[f]	0.82±0.13 (±0.10)	59 ±8 (±10)	60	0.018±0.003	1.27±0.21	1.29
03-401[c]	2200	1962	3	-	2.24±0.35 (±0.40)	-	-	0.37 ±0.07	-	-

[a] The values of the standard errors derived from multiple measurements are given in parentheses.

[b] The values of the errors for total elimination are essentially identical to those for the corresponding fecal values.

[c] These subjects resided in an area with high ^{226}Ra content in the drinking water [Ottawa (6 pCi/L), Marseilles, Illinois, (> 6 pCi/L)] (Ref. 11), so that the normal ^{226}Ra fecal and urinary excretion rates were assumed to be 5±1 and 0.05±0.05 pCi/day, respectively.

[d] Only the mean value for case 05-284, 5.67% per yr is used in calculating the overall mean for this table.

[e] This value was not used in the calculations as the patient was immobilized in a hospital (see text).

[f] See Ref. 3.

Table 6. ^{226}Ra elimination rates and coefficients of elimination for medical cases

Case No.	Sex	^{226}Ra body content, nCi	Year of collection	Sample size, day		Excretion rates, pCi/day ±S.E.[a] (corrected for natural levels)			Coefficients of elimination, % ^{226}Ra content/yr		
				Urine	Feces	Urine	Feces	Total[b]	Urine	Feces	Total[b]
01-184	M	48	1968	3.0	2.0	0.010±0.010	-0.09±0.52	- 0.08	0.008±0.008	-	-
01-157	F	49	1966-1972	17.8	7.0	0.041±0.011	0.52±0.54	0.56	0.031±0.009	0.39 ±0.40	0.42
01-196	M	69	1970	27.1	3.21	0.12 ±0.017 (±0.009)	4.2 ±0.93	4.3	0.061±0.011	2.2 ±0.53	2.3
			1972	5.0	3.58	0.051±0.013 (±0.013)	1.86±0.65 (±0.73)	1.91	0.027±0.007	0.099±0.36	1.02
01-558	M	362	1973	9.06	6.08	0.14 ±0.02 (±0.02)	6.5 ±1.1 (±1.0)	6.6	0.014±0.002	0.66 ±0.13	0.67
03-139	M	390	1970	14.0	14.0	0.12 ±0.02 (±0.03)	12.3 ±1.6 (±1.5)	12.4	0.011±0.002	1.15 ±0.19	1.16
03-125	F	650	1970	14.0	13.2	0.33 ±0.04 (±0.04)	18.2 ±2.2 (±2.8)	18.5	0.019±0.003	1.02 ±0.16	1.04
01-520	F	670	1967	2.87	9.0	1.28 ±0.20	25.9 ±3.3 (±7.5)	27.2	0.070±0.013	1.41 ±0.22	1.48
01-144	F	762	1968	7.0	6.0	0.41 ±0.05	29.1 ±3.9 (±0.5)	29.5	0.020±0.003	1.39 ±0.23	1.41
		694	1971	10.6	10.0	0.20 ±0.026 (±0.015)	17.3 ±2.2 (±4.6)	17.5	0.011±0.002	0.91 ±0.15	0.92
03-115	F	730	1970	14.0	10.9	0.27 ±0.03 (±0.03)	15.4 ±2.0 (±0.4)	15.7	0.014±0.002	0.77 ±0.13	0.79
01-431	F	880	1966	3.0	-	0.27 ±0.04	-	-	0.011±0.002	-	-

Table 6 (cont.). ^{226}Ra elimination rates and coefficients of elimination for medical cases

Case No.	Sex	^{226}Ra body content, nCi	Year of collection	Sample size, day		Excretion rates, pCi/day ±S.E.[a] (corrected for natural levels)			Coefficients of elimination, % ^{226}Ra content/yr		
				Urine	Feces	Urine	Feces	Total[b]	Urine	Feces	Total[b]
03-135	M	1020	1970	13.0	14.0	0.28±0.03 (±0.06)	36.4±4.3 (±4.6)	36.7	0.010±0.002	1.30±0.20	1.31
10-825	M	1070	1976	9.7	10.85	0.58±0.07 (±0.04)	23.1±2.9 (±4.6)	23.7	0.020±0.003	0.79±0.13	0.81
			1977	7.57	8.4	0.44±0.06 (±0.04)	16.6±2.2 (±2.8)	17.0	0.015±0.002	0.57±0.09	0.58
01-017	F	1300	1969	27.3	7.0	1.47±0.16 (±0.09)	31.6±4.1	33.1	0.041±0.006	0.89±0.15	0.93
		1270	1971	8.7	11.0	1.74±0.21 (±0.34)	35.6±4.3 (±2.5)	37.3	0.05 ±0.008	1.02±0.16	1.07
		1120	1976	7.9	1.0	1.37±0.17 (±0.19)	13.1±3.2	14.5	0.045±0.007	0.43±0.11	0.47
03-116	F	1450	1970	14.0	12.0	0.57±0.07 (±0.23)	29.9±3.6 (±3.1)	30.5	0.014±0.002	0.75±0.12	0.77
03-206	M	3300	1973	6.7	5.6	1.26±0.16 (±0.19)	65.5±8.7 (±15.1)	66.8	0.014±0.002	0.72±0.12	0.74
10-010	F	8600	1972	5.0	8.0	2.95±0.40 (±0.06)	170 ±20	173	0.013±0.002	0.72±0.11	0.73

[a] The values of standard errors derived from multiple measurements are given in parentheses.

[b] The values of the errors for totals are essentially identical to those for the corresponding fecal values.

Table 7. ^{226}Ra elimination rates and coefficients of elimination for radium chemists

Case No.	Sex	^{226}Ra body content, nCi	Year of collection	Sample size, day		Excretion rates, pCi/day ±S.E.[a] (Corrected for natural levels)			Coefficients of elimination, % ^{226}Ra content/yr		
				Urine	Feces	Urine	Feces	Total[b]	Urine	Feces	Total[b]
01-205	M	15	1971	1.95	1.0	0.035±0.013	0.31±0.58	0.34	0.085±0.032	0.75±1.4	0.84
01-408	F	20	1966	5.77	5.0	0.036±0.012 (±0.005)	0.36±0.53	0.40	0.066±0.022	0.66±1.0	0.72
05-127	M	20	1967	3.0	3.0	0.033±0.011	0.24±0.53	0.28	0.060±0.023	0.44±0.98	0.50
01-356	M	23	1969	1.96	-	0.060±0.016	-	-	0.11 ±0.03	-	-
01-521	M	24	1967, 1972	4.78	3.0	0.011±0.010 (±0.011)	0.57±0.54	0.58	0.011±0.010	0.87±0.85	0.88
01-410	F	51	1966	6.0	7.0	0.062±0.014	2.06±0.63 (±0.46)	2.06	0.044±0.011	1.48±0.48	1.52
01-530	M	52	1968	1.92	1.0	0.28 ±0.05	3.26±1.07	3.54	0.19 ±0.04	2.29±0.79	2.49
01-330	M	66	1976	8.8	3.56	0.074±0.014 (±0.050)	2.36±0.70	2.43	0.041±0.009	1.31±0.41	1.34
01-177	M	61	1969	1.86	-	0.099±0.022	-	-	0.059±0.014	-	-
05-383	F	73	1973	5.66	1.5	0.085±0.016	4.80±1.22	4.89	0.043±0.009	2.40±0.65	2.44
01-522	M	240	1968	2.0	-	0.50 ±0.09	-	-	0.076±0.016	-	-
01-208	M	900	1967	6.77	-	1.90 ±0.24 (±0.04)	-	-	0.077±0.012	-	-
		850	1969	12.7	-	0.73 ±0.08 (±0.16)	-	-	0.031±0.005	-	-
		818	1971	2.89	6.0	0.93 ±0.15	19.8 ±2.7 (±4.9)	2.07	0.041±0.008	0.88±0.15	0.92

[a] The values of standard errors derived from multiple measurements are given in parentheses.

[b] The values of the errors of the totals are essentially identical to those for the corresponding fecal values.

contents less than 1500 nCi, only the urinary rate of the dial painters differed significantly from zero (0.16 ± 0.06 pCi/day). Finally, the exact value of this normal rate does not affect the results substantially; a value for the fecal excretion rate of 2 pCi/day does not change the overall conclusions.

Uncertainties, i.e. standard deviations (±S.D.), of individual elimination rates were obtained by propagation of the ±10% error mentioned earlier on the analytical method and the collection period, a 20% standard deviation to account for day-to-day variability in excreted ^{226}Ra, and the standard deviation (± SD_E) of the assumed normal excretion rate (E).* Thus,

$$SD = \pm\left\{\left(\frac{Ra}{t}\right)^2 [(0.10)^2 + (0.20)^2/t] + SD_E^{\,2}\right\}^{1/2}, \qquad (1)$$

where Ra is the amount of ^{226}Ra determined in a sample,

t is the time in days over which the sample was collected, and

0.10, 0.20 and SD_E are standard deviations as noted above.

The values of normal daily excretion rates and SD_E are assumed to be

1.0 ± 0.5 (SD_E) pCi/day in feces, and

0.01 ± 0.01 (SD_E) pCi/day in urine, except that in the Ottawa area they are assumed to be:

5 ± 2 pCi/day in feces, and

0.05 ± 0.05 pCi/day in urine.

When more than one sample from a given collection period was measured, the variability is given by the standard error of the measurement (±S.E.) in parenthesis after the calculated S.D. in Tables 5-7. For the dial painters, the calculated and observed S.D.'s are very similar; the mean values are 3.91 ± 0.81 for the observed S.D. and 3.95 ± 0.91 for the calculated S.D. The root mean square deviation (difference between observed and calculated) was 0.90 ± 0.75 for those subjects for whom observed standard deviations were available.

While the ^{226}Ra urinary excretion rates are low compared to the fecal rates, the urinary levels are still sufficient for reasonably accurate determinations (>0.010 pCi/sample). In most cases the fecal excretion

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*Suggested by A. T. Keane of this Laboratory.

represents more than 90% of the total elimination. For one dial painter, 03-402, with collections separated by 2 yr, the fecal rates of ^{226}Ra (and also of ^{210}Pb) differed by a factor of 6. The higher rate (not used in the calculations) occurred when she was confined to a hospital bed and probably represents increased bone resorption associated with disuse osteoporosis.

The excretion rates were expressed as "coefficients of elimination" of the ^{226}Ra body content, CE, defined as

$$CE = -\frac{dR}{dt}/R \quad , \tag{2}$$

the fractional elimination rate of the nuclide. This quantity represents the instantaneous fractional rate of change of body content. In this paper coefficients of elimination are expressed as percent of body content eliminated per year.

The individual urinary, fecal and total coefficients of elimination are presented in Tables 5-7 along with the elimination rates (E). The unweighted means for each group are presented in Table 8. The coefficient of variation (fractional standard deviation) of each elimination rate was propagated with a nominal coefficient of variation of 0.1 in the value of the ^{226}Ra body content to obtain the standard error of the CE, i.e.

$$SE_{CE} = \pm CE \left[\left(\frac{SD}{E}\right)^2 + (0.1)^2\right]^{1/2} \quad , \tag{3}$$

where SD is the standard deviation of the excretion rate defined in Eq. 1 and E is the elimination rate.

The use of the mean of the CE's weighted by the inverse variances of the individual data points gives lower (but not significantly) values for the medical cases and chemists. The weighted means of the total elimination rate were 0.81 ± 0.06 and 1.09 ± 0.15% per yr for the two groups, respectively, which may be compared to the respective unweighted means of 0.98 ± 0.10 and 1.30 ± 0.23% per yr. However, for the dial painters the differences between the weighted and unweighted mean values for total are substantial, 1.10 as compared to 2.23% per yr, respectively. The lower value is essentially identical to those of the other groups, while the higher one is significantly greater ($P \approx 0.05$). Because the variance of a result is approximately

Table 8. Coefficients of Elimination.

Group	Sex	Mean coefficients of elimination (unweighted), % ^{226}Ra content/yr ±SE(n) Urinary(U)	Fecal(F)	Total[a]	Ratio, U/F
Dial painters	F	0.11 ± 0.02(33)	2.12 ± 0.39(23)	2.23	0.052 ±0.013
Medical cases	M	0.020 ± 0.005(9)	1.05 ± 0.19(8)	1.07	0.019 ±0.006
	F	0.028 ± 0.006(12)	0.88 ± 0.10(11)	0.91	0.032 ±0.008
	M + F	0.025 ± 0.003(21)	0.95 ± 0.10(19)	0.98	0.026 ±0.004
Radium chemists	M	0.071 ± 0.015(11)	1.09 ± 0.27(6)	1.16	0.065 ±0.021
	F	0.051 ± 0.008(3)	1.51 ± 0.50(3)	1.56	0.034 ±0.005
	M + F	0.067 ± 0.012(14)	1.23 ± 0.23(9)	1.30	0.054 ±0.014
			Weighted mean (Groups)[b]		0.030 ±0.007

[a]The SE values for these results are essentially identical to those for the feces.

[b]Weighted by the inverse variances for the three groups not broken down by sex.

proportional to the value of the result itself, the weighted mean gives higher weights to the lower values. This tends to obscure the fact that for the dial painters a substantial fraction (65% compared to 10 and 33% for the medical cases and chemists, respectively) of the CE's are high (> 1.5% per yr). The use of other weighting methods, such as the weights proportional to the body content of ^{226}Ra and collection time, or the use only of data from subjects with body contents of ^{226}Ra greater than 50 nCi resulted in final conclusions similar to that from the unweighted mean.

The wide variations between the averages of the fecal CE's of the dial painters calculated in different ways arise from the distribution of these

values as shown in Figure 1. While the distribution could be interpreted as being lognormal, with the higher values of CE being in the tail of the distribution, the flatness of the tail indicates that the results fall into two populations, with values below and above 1.5% (6 and 12 cases, respectively). The distribution in the lower group is similar to those in the medical cases and chemists.

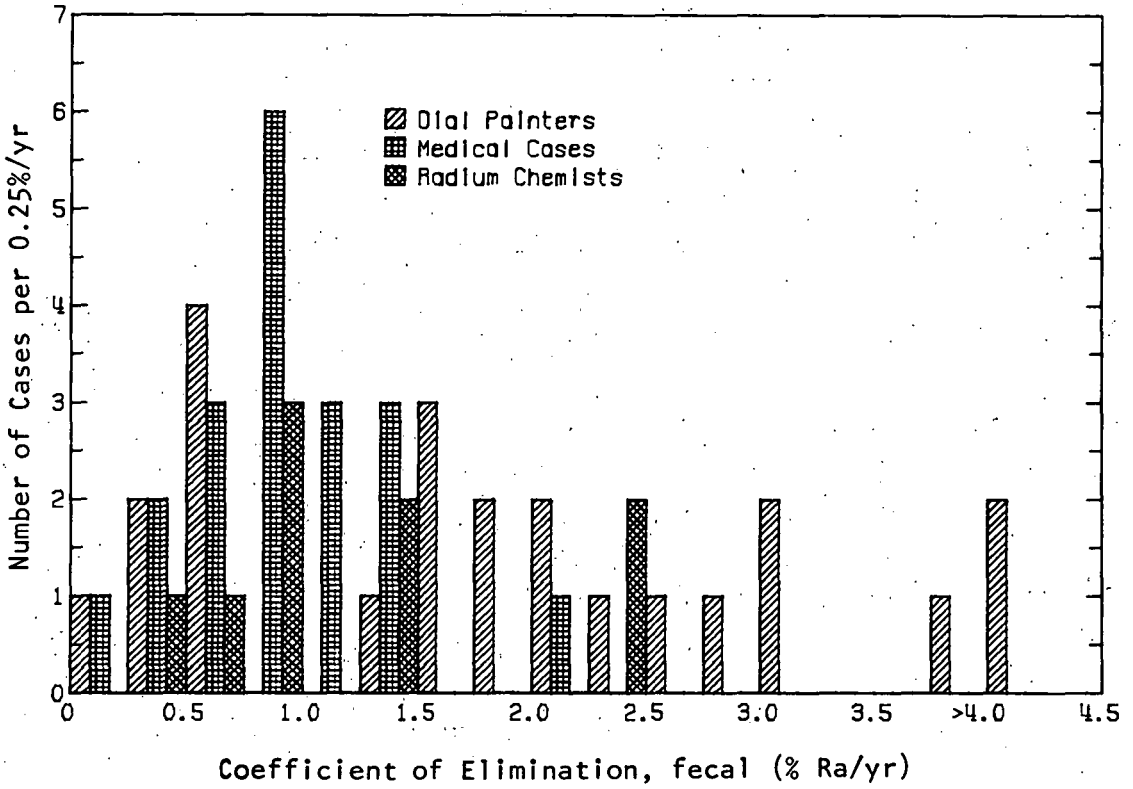

FIG. 1.--Distribution of the fecal coefficients of elimination for dial painters, medical cases, and chemists.

While the parameters in Table 1, such as age at mid-exposure and body content at the time of the collection, do not differ between the groups, there is an indication that the group with the higher levels of CE was younger at mid-exposure (mean age ± SE of 19.2 ± 0.46 yr, n = 12) than that with CE's below 1.5% per yr [mean age ± SE of 23.7 ± 2.4 yr, n = 6, P ≅ 0.08, or if the age of case 05-215 (35 yr) is excluded from the calculations 21.4 ± 1.03 yr, n = 5, P ≅ 0.10].

A similar effect is indicated in the values of the urinary CE's with a separation at about 0.1% per yr. The subjects with the higher values of urinary CE's also appear to be in the group with the higher fecal values, but there are too few data points to substantiate this.

Since a large fraction of the dial painters appear to have higher values of CE's, we will use the higher value (mean) of the CE's for the dial painters. By Student's t-test the total and fecal coefficients for the dial painters are significantly greater than the respective ones for the medical cases ($P < 0.01$, total; $P < 0.02$, feces), and they are probably significantly greater than those of the chemists ($P \cong 0.05$).* The medical subjects exhibit more uniformity in their coefficients, as noted by the smaller relative standard errors (Table 8). The lower variability of the excretion rates for the medical cases compared to that of the rate for the dial painters is illustrated in the plots for the respective groups of excretion rates as a function of body content in Figures 2 and 3. (The ratios of the y intercepts to the x intercepts or slopes on a linear scale, of the lines are proportional to the coefficients of excretion: CE = Slope x 36.5.)

The urinary excretion rates are plotted against the fecal rates in Figure 4 for each subject. A least squares fit of a straight line to the data resulted in the regression equation:

$$U = (0.0171 \pm 0.0016)\ F + (0.16 \pm 0.05)\ \text{pCi/day},$$

where U and F are the urinary and fecal excretion rates in pCi/day, respectively. The linear coefficient of correlation, r, was 0.83 ($P<0.01$, $n=50$). Shown on the figure is the linear fit forced through the origin

$$U = (0.0198 \pm 0.0014)\ F\ \text{pCi/day},$$

with $r = 0.89$ ($P < 0.01$, $n = 50$). This equation appears to be more reasonable than the previous one, which implies a significant urinary excretion rate when the fecal excretion rate in excess of that from environmental levels is very low (< 1 pCi/day).

The means of the ratio U/F differ among the groups, being highest in the chemists and lowest in the medical cases, but the differences are not significant (Table 8). The overall mean weighted by the inverse variances is 0.030 ± 0.007 (±SE). While this value is 50% greater than that derived from the least squares analysis, the two values do not differ significantly ($P > 0.05$). The values for the urinary rates may be upper limits, owing to

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*While this test is valid only for populations with similar variances, $\sigma_1^2/\sigma_2^2 \gtrsim 1$ it is still valid for widely discrepant variances if one reduces the number of degrees of freedom (Ref. 13, pp. 397-398).

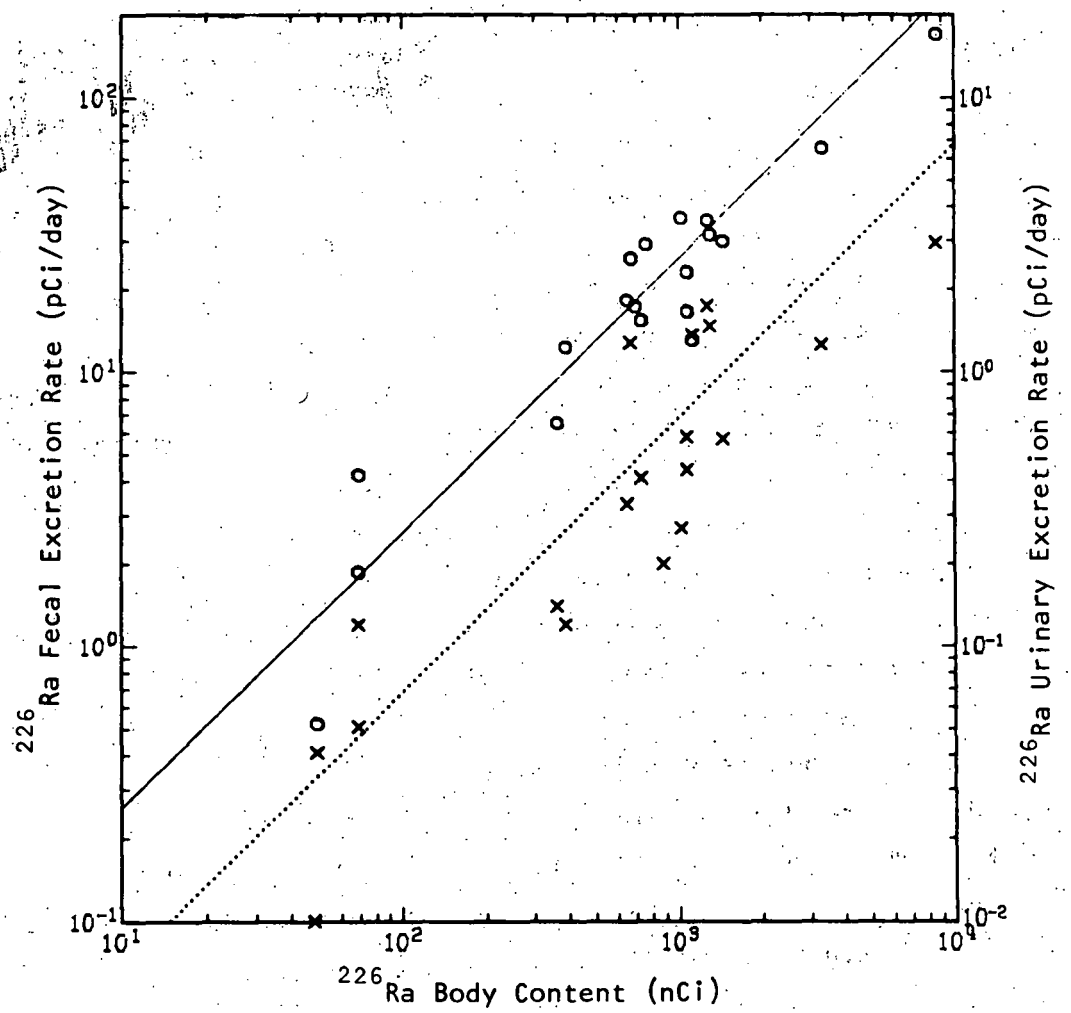

FIG. 2.--Urinary and total (urinary plus fecal) excretion rates versus ^{226}Ra body content for the medical cases. The straight lines represent least square fits of log y = log a + log x or of y = ax to the data. -O- Feces (Slope = 0.026 pCi d^{-1} nCi^{-1}); •••X•••Urine (Slope = 0.00068 pCi^{-1} d^{-1} nCi^{-1}).

analytical problems; the levels in urine are often low and near the limits of detection (about 0.010 pCi in a sample). Older samples (processed before 1973) may be subject to contamination from reagents. These effects are particularly significant for the chemists, who generally had lower ^{226}Ra body contents.

Comparison of the measured coefficients of excretion with those predicted by the Norris power function that describes the retention of ^{226}Ra in the body as a function of time after intake[14] is a check on the validity of this function. This function is particularly relevant because it is used to estimate the body content at the time of intake from measurements made 20 to

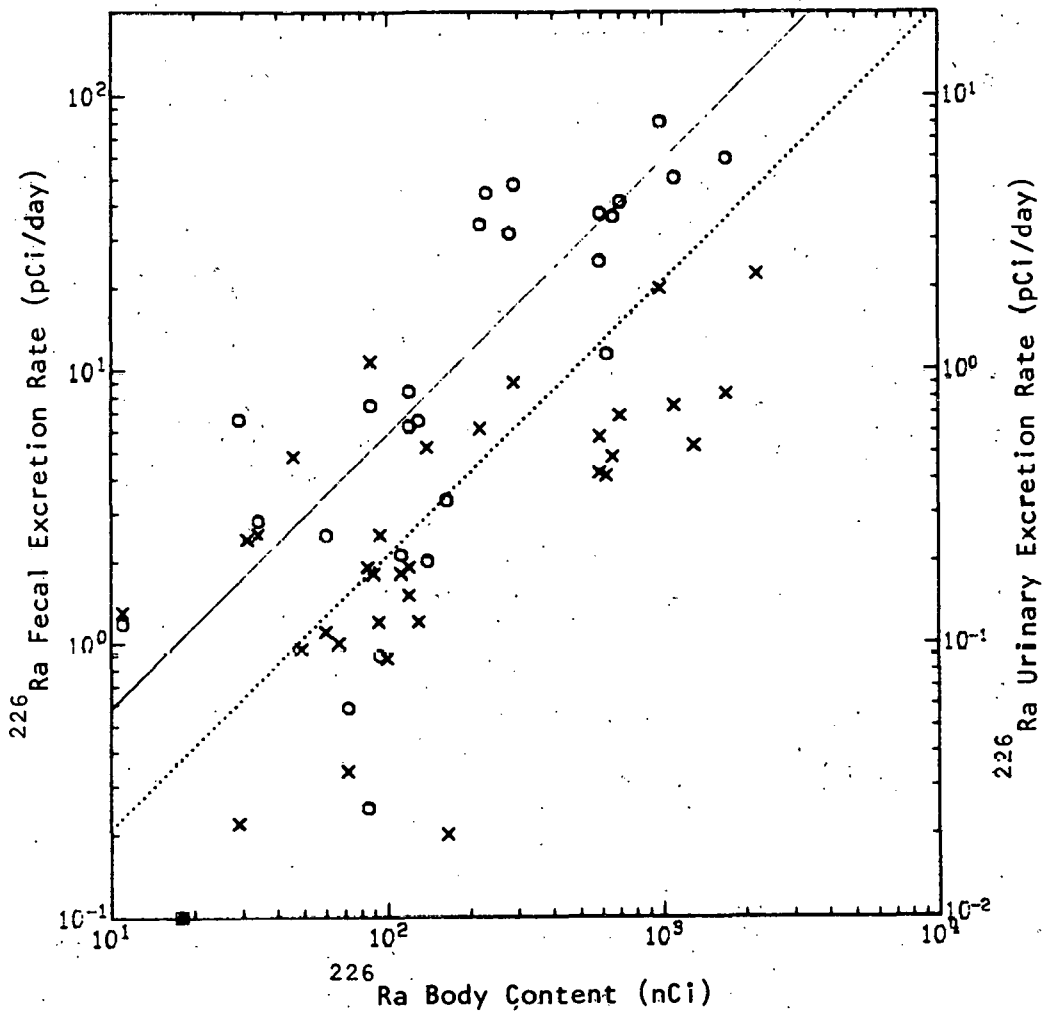

FIG. 3.--Urinary and fecal excretion rates versus ^{226}Ra body content for the dial painters. The straight lines represent least squares fits of log y = log a + log x or y = ax to the data. The slope of the line for the urinary data is the geometric mean of the coefficients of elimination and it rather than the arithmetic mean, is used because of the better fit to the data it provides. -O- Feces (Slope = 0.058 pCi d^{-1} nCi^{-1}); •••X•••Urine (Slope = 0.0021 pCi d^{-1} nCi^{-1}).

60 years later and to calculate the radiation dose to the skeleton. The power function is given as

$$R_t = A \cdot t^{-b} \quad , \tag{4}$$

where R_t is the fractional retention of the ^{226}Ra in the body at time t, A is the fractional retention at one day after intake, t is the time in days since uptake, and b is a constant. The Norris values are 0.54 for A and 0.52 ± 0.05 for b.[1]

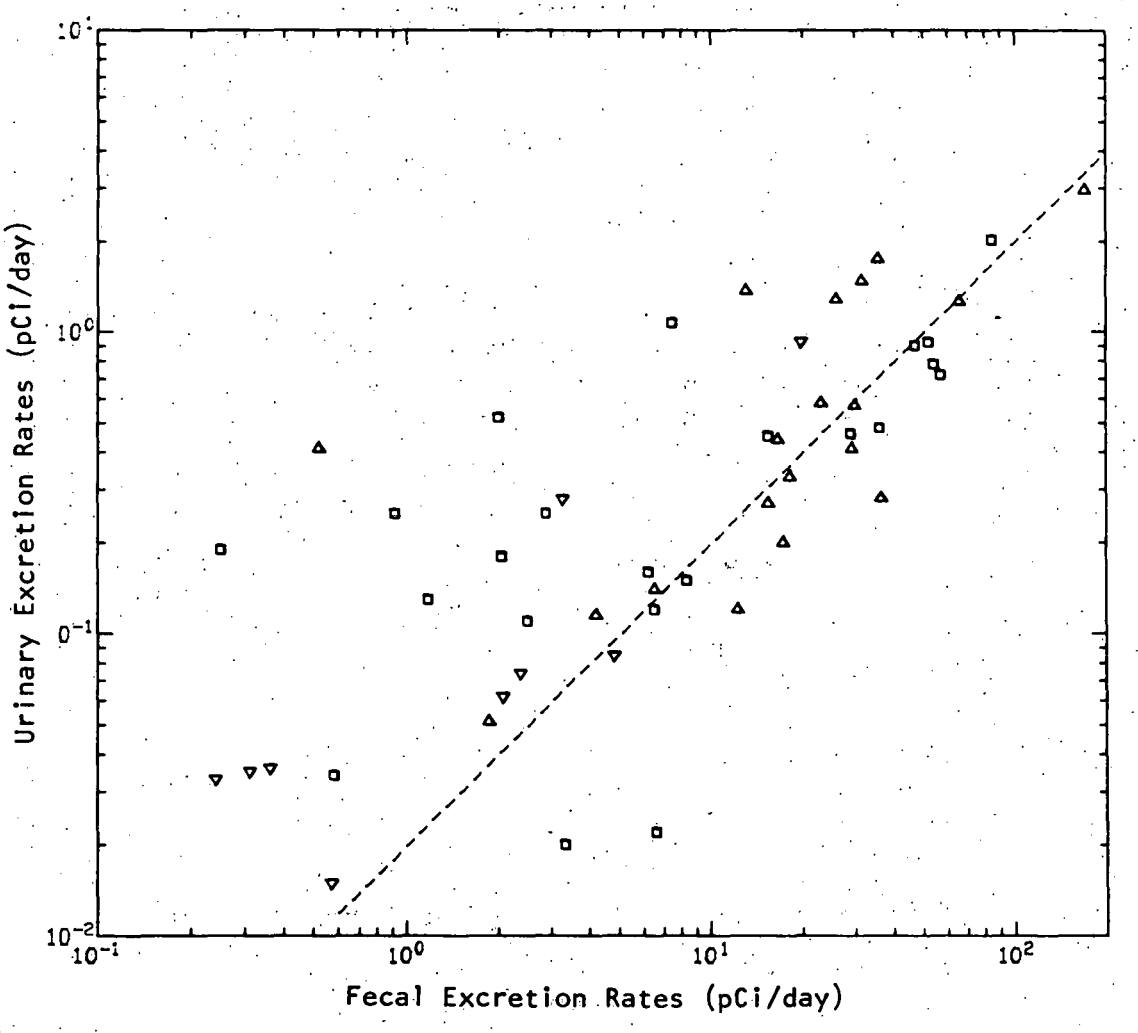

FIG. 4.--Urinary versus fecal excretion rates of ^{226}Ra for the three groups. The straight line represents a least squares fit of the equation U = 0.0198F to the data. □ Dial painters; Δ Medical cases; ∇ Radium chemists; ••• U = 0.0198F.

The elimination rate is the first derivative of this function, with a negative sign,

$$- \frac{dR}{dt} = A \cdot b \cdot t^{-b-1} \quad , \tag{5}$$

and the coefficient of elimination, CE, is the fraction of the body content excreted per unit time (Eq. 2),

$$CE = - \frac{dR}{dt} / R = \frac{b}{t} \quad . \tag{6}$$

Thus, the CE is predicted to change inversely with time, from 5.2% per yr at 10 years after intake, to 1.04% per yr at 50 years. For the dial painters [mean time of 43 yr since exposure (Table 4)] the mean of the ratios of the measured (Table 8) to the expected coefficients of elimination is 1.9 ± 0.3 (S.E.). On the other hand, for the medical cases (42 yr since exposure) the CE of 0.97% per yr is 0.78 ± 0.06 of that calculated. Similarly, for the chemists, the mean CE of 1.30% per yr is 0.75 ± 0.16 of that expected 30 yr after exposure, a value not quite significantly different from 1.0. However, in the latter group, removal of one high value of the ratio of 2.6 (case 05-383) gives a value of the mean (0.62 ± 0.11), which is significantly less than the expected ratio of 1.0. It should be noted that these ratios of observed to calculated values are similar regardless of whether one uses the ratios of the means in Table 8 at the mean time or the means of the ratios for each subject (Tables 5-7).

The data collections from individual subjects over a period of years are not conclusive in characterizing changes in the excretion rates with time. For the dial painters the fecal CE's decrease in two cases, increase in two cases and are approximately constant in one case, while the urinary CE's decrease in four cases, increase in one and are constant in another. For the one medical case with multiple measurements there were indications of a decrease in the fecal, but not in the urinary CE, while for the one chemist there was an indication of decreased urinary excretion rates with time.

To observe a significant change in the value of CE of about 30% (twice the estimated uncertainties in the determination of the excretion rates), it may be necessary to make measurements 10 to 12 yr apart (Eq. 6). However, similar or improved accuracy may be obtained with multiple measurements over a shorter period of time, e.g., five studies in five years, and such a possibility should be examined.

The variabilities of the ratios of observed-to-expected values of CE are probably largely due to biological variability and secondarily to the uncertainties in the times of collection. That the coefficients for the medical cases and chemists are lower than expected from the Norris function suggests that the value of the exponent b may need some adjustment; possibly it should be 20% lower. In most of these cases the ratio was less than one; for only one of nine chemists was the ratio greater than 2.0, and for only three of the 18 ratios for the medical cases were the values greater than

unity. This conclusion is consistent with that of Miller and Finkel[15] that the retention function should be

$$R = 0.30t^{-0.44} \quad , \tag{7}$$

or possibly even

$$R = 0.20t^{-0.36} \quad . \tag{8}$$

The values of the exponents in Eqs. 7 and 8 are consistent with that of b (0.41), the exponent of the power function term in the ICRP 20 model.[16] However, the values of the parameters of ICRP 20 were not independently determined since they are also based on Miller and Finkel's data,[6] among those from other workers, which are from iatrogenic cases. Some of our cases (the subjects with case numbers 03-115 to 03-139) are also in the above group. The conclusions on the similarities in the values of the parameter are strengthened, however, since they are derived by two quite different methods, i.e., repeated whole body counting, and determination of excretion rates.

On the other hand, for the dial painters 14 of 21 values are greater than unity, the CE's range up to 8.6% per yr, and the mean value of CE x t is substantially greater than the exponent of the Norris function. The mean values of b estimated from the total CE's in Table 8 at the mean time since intake (Table 4) and Eq. 6 are 0.96 ± 0.17, 0.41 ± 0.04 and 0.35 ± 0.07 for the dial painters, medical cases and chemists, respectively. Thus, as shown in Table 9 the CE's for the two latter groups are consistent with the Miller and Finkel parameters, while that for the dial painters is substantially greater than those and that of the Norris function. The CE's of the dial painters are consistent with those expected from the ICRP 20 model that includes an exponential factor with a decay constant (λ) that at long times after intake predicts a loss of 1.5% per yr. The observed CE's for the medical cases and chemists are consistent with the ICRP 20 model in which the value of λ is near zero.[16] The values of the initial retention (at one day), A, in Eq. 4 cannot be determined from these data.

The large value of b for the dial painters indicates a significant departure from the extrapolated Norris function, i.e., that the dial painters are excreting radium at an increased rate, and it suggests a change towards an

Table 9. Comparison of predicted with observed coefficients of elimination.

Group	Time since exposure, yr	Coefficients of elimination, %/yr				
		Observed	Expected from models			
		(Table 8)	Norris (b=0.52)	ICRP 20 (λ=1.5, b=0.41)	ICRP 20 (λ=0, b=0.41)	Miller (Eq.9, b=0.36)
Dial painters	44	2.3	1.2	2.7	0.97	0.82
Medical cases	42	0.98	1.2	2.8	0.92	0.86
Radium chemists	27	1.30	1.9	3.9	1.7	1.3

exponential function of time as predicted by the ICRP 20 model of alkaline earth metabolism.[16] This effect is even more significant if only the group with the larger values of CE is considered. According to that model the CE should be about 3% per yr at 40 yr after intake (Fig. 22, p. 189 of Ref. 16). A value of b of ~ 1 (i.e., 0.92) indicates that the loss is exponential, according to one theory that derives the power function from chemical kinetic principles.[17]

The differences in the values of the b's may be due to the dial painters having acquired radium much younger than the other groups (19 yr compared to 24 yr and 30 yr for the medical cases and chemists, respectively). The effect of age at acquisition on retention (but not the effect on CE) was discussed in ICRP 20 (Ref. 16, pp. 180-190). Higher ratios may also reflect the exponential loss of radium at late times predicted by the retention equation of ICRP 20 and attributed to various aspects of the loss of radium and its being recycled in the skeleton. Loss of bone mass, as in osteoporosis, may lead to a similar retention function which is explained by a chemical kinetic mechanism of higher order (> 3) that controls the kinetics of the tracer (^{226}Ra) in a poorly mixed medium (bone) at early times and is described by a power function. At later times the loss of bone mass through osteoporosis may become the rate-controlling mechanism with the radium tracer then following apparent first order kinetics (exponential loss.)[17]

The cause of the differences between the groups is not obvious. One possibility is that at the earlier age of acquisition by the dial painters, the higher metabolic rates of the less mature bone may have distributed the

radium more uniformly in the skeleton, so that apparent first order kinetics (exponential loss) would occur sooner after the end of exposure. While on the one hand this hypothesis is not supported by the data (that is the correlation between CE and age at acquisition is not statistically significant), on the other hand such a relationship could be obscured by the narrow range of ages. Some support is given by the slight difference in age noted between dial painters with CE's above and those with CE's below 1.5% per yr. In addition, since the skeleton is approaching maturity at this time, small variabilities in the age of maturation (relative to an average life-span) could be a large fraction of the duration of exposure. Also there is no correlation between duration of exposure and CE.

The results for dial painters are consistent with those of Lucas et al.[3] with a mean CE of 2.5% per yr at 43 yr after intake (the values are not entirely independent since their four cases are included in ours). For the data of Norris et al.,[1] which were for iatrogenic cases, the CE was 2.9% per yr after 23 yr, which implies a value of b of about 0.67, compared to our value of 0.41 at 42 yr. Lucas et al.[3] attributed the closeness in values of the CE of Norris et al. at 23 yr to theirs at 43 yr to the possibility of a final exponential retention term. However, our results indicate that the similarities in excretion rates at different times may be due to the mode of (or age at) uptake.

Most of the cases described by Muth and Oberhausen[2] are not comparable to ours, since they were working with radium or had ceased exposure just prior to measurement. However, one subject (a pharmaceutical worker with a ^{226}Ra body content of 16,500 nCi) had ended a 35-yr exposure 6 yr prior to measurement. Her value of CE of 0.58% per yr was consistent with those of some of our cases.

Conclusions

From these results it appears that the three groups differ in their metabolism of radium. The chemists show coefficients of fecal elimination similar to those of the medical cases, particularly when consideration is given to the shorter times since exposure of the chemists. For the chemists and dial painters, the coefficients of urinary elimination are similar, and they are greater than those of the medical cases. The urinary excretion rates are 1.9 to 5.4% of those of the fecal rates, with a weighted mean of 3.0 ±

0.7% (±S.E.) (the mean of the values in column 5 of Table 8, weighted by their respective inverse variances).

The causes of the metabolic differences among the groups are not evident. Sex differences do not appear to be a factor, as evidenced by the medical cases. The mean total CE of ^{226}Ra (±S.E.) for the eight females (for whom we had data on the feces) of 0.9 ± 0.1 did not differ significantly from the 1.1 ± 0.2% per yr for the six males. Similarly, but less significantly (because of fewer cases), for the chemists the mean CE for the three females was 1.5 ± 0.5% per yr compared to 1.2 ± 0.2% per yr for the six males.

The difference could result from such causes as age at the time of acquisition, rate or mode of acquisition and the amount of physical activity performed by the subjects, both during the period of intake and at the time of collection of excreta. Definite conclusions must await further data and more detailed analyses of the results.

As a test of the retention models at long times (~ 40 yr) after the end of exposure, these results show that the Norris function, which is used in calculating dose to the CHR subjects, on the average predicts values of CE similar (± 50%) to those observed for the medical cases and chemists (± 50%), and for the dial painters within a factor of two. On the other hand, the ICRP 20 model with λ = 1.5% per yr predicts values of CE about three times those observed for the medical cases and chemists, but its predictions are only 20% greater than those observed for the dial painters. This model could be adjusted to fit the results for the medical cases and chemists by reducing the value of λ ($\lambda \simeq 0$), at which point (at long times after intake) it approximates a power function (Eq. 4) with parameters very similar to those of the Norris function.

The results of the measurements reported here are useful in the dosimetry of the radium patients in that the coefficient of elimination is an instantaneous rate of change from which the value of the parameter b in Eq. 6 can be obtained for a given individual. This value should be similar to that derived from serial whole body counting measurements made over many years (10-15 yr) near the time of the CE measurements for such a subject. Where protracted whole body measurements are impossible, excreta data are then the only source of such information on rates of change in body content. Both methods have uncertainties that may be reduced by judicious combination of results from both types of measurements. Individual values of b can be used

to estimate more accurate values of absorbed dose in the radium patients.

Further analyses of the existing metabolic data and studies on the normal environmental levels should help in making these results more accurate and useful.

Acknowledgement

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Finally we wish to thank the director and staff of Manteno State Hospital for the use of their metabolic ward in the study of five of the medical cases, and the director of Elgin State Hospital for arranging for those patients to participate in the study.

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RADON IN HOUSES - A REVIEW*

J. Rundo and R. E. Toohey

Energy-conservation measures that result in less ventilation of dwellings with outside air may lead to increased concentrations of radon indoors and therefore possibly to an increased incidence of lung cancer. As a result, there is currently considerable interest in radon in houses, both nationally and internationally. Our own measurements have shown that in some houses the natural radon concentration routinely exceeds that for which the Surgeon General stated that remedial action was indicated in the case of houses built in Grand Junction, CO, on uranium mill tailings (10 pCi/L, with the short-lived daughter-products assumed to be at 50% of equilibrium).[1]

The sources of indoor radon include soil gas, building materials, water usage, and ground water; infiltration routes include diffusion, cracks, floor-wall joints, loose pipes, floor drains, drain tiles, and crawl spaces.

A common measurement technique is to determine the α-activity of an air sample in a Lucas counter[2] or similar device; however, "grab" samples are unsatisfactory because of temporal and spatial variations in radon levels even within a small volume (one room of a house), and the number of samples which can be taken is limited by the availability of counting equipment. Consequently, devices which measure more or less continuously the varying radon levels are preferred. These include detectors which count radon α-particles exclusively,[3] and those which count the α-particles produced from radon and especially its daughters in a defined volume.[4] The concentrations of radon daughters can be determined independently of the radon levels by collecting, on filters, the aerosol particles to which the daughters are attached and counting the α-particles from the latter. Although radon instruments can be intercalibrated, no method has yet been devised to intercalibrate widely separated instruments which measure the daughters.

*Summary of an invited paper presented at the 26th Annual Meeting of the Health Physics Society, Louisville, KY, June 21-25, 1981.

The concentrations of naturally occurring radon in houses are extraordinarily variable. In our own ongoing study of houses in the vicinity of Argonne, levels have ranged from 0.05 to 54.5 pCi/L, with a geometric mean of 1.1 pCi/L, and a geometric standard deviation of 3.2. Levels seem to be related to the type of soil under the house, but there is still great variability in a given house. We have looked for correlations between radon concentrations and meteorological variables such as pressure, atmospheric stability, and wind speed and direction, with little success.

Because radiation dose received by the lung is due almost entirely to the short-lived daughters of radon, rather than to radon itself, it is useful to introduce a parameter known as the equilibrium factor, or working level ratio, F. One working level (WL) is defined as that concentration of short-lived radon daughters in any combination, which has a potential alpha-particle energy of 1.3×10^5 MeV per liter of air. Since this is the equivalent of 100 pCi/L of radon with all its daughters in equilibrium,

$$F = 100 \text{ WL/Rn (pCi/L)}.$$

Values of F reported by other workers seem to have a mean of 0.5, but sometimes this was an assumed value. It is of interest to note that values reported from Italy were all < 0.5 for mines and < 0.05 for spas.[5] We have also found low values for F ranging from 0.05 to 0.25 when houses have been closed for heating or air conditioning. Some preliminary measurements have indicated that the missing daughters are located on surfaces in the house, and the total amount calculated to be on surfaces is of the right order.

There are two major tasks which must be accomplished in order to determine the radiation dose received by the general population from naturally occurring radon. The first is an extensive survey of radon concentrations in houses under different conditions of ventilation with outside air and at different times of the year. The second is an intensive study of the value of F in houses and the effects on it of location (urban or rural), ventilation, air circulation, and aerosol concentration.

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EXCRETION OF ^{210}Pb BY WORKERS IN AN AREA WITH HIGH LEVELS OF ATMOSPHERIC RADON, AND ESTIMATES OF EXPOSURE TO SHORT-LIVED RADON DAUGHTERS*

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The urinary excretion rates of ^{210}Pb were used to estimate the exposures to ^{222}Rn and its short-lived daughter products for 12 persons who had been working for about nine years at an industrial site formerly utilized for the processing of uranium ores and for the dumping of process residues. Measurements of body radioactivity in a low-background counting facility showed no levels in excess of normal, but the geometric mean excretion rate of ^{210}Pb of 0.86 pCi/day was significantly above the normal environmental level of about 0.2 pCi/day; the geometric standard deviation was 2.0. The excretion rates of both ^{210}Po and ^{226}Ra of 1.37 and 0.10 pCi/day, respectively, were also substantially above their respective normal environmental levels of 0.2 and 0.02 pCi/day.

A metabolic model was proposed to relate the urinary excretion rates of ^{210}Pb to exposures to radon, short-lived radon daughters and ^{210}Pb present in the atmosphere. This model predicts, for reasonable conditions, such as an effective age of the air of 30 min and a moderate disequilibrium between radon and its short-lived decay products (F = 0.44)†, that most of the ^{210}Pb is derived from the ^{222}Rn dissolved in body fluids. Based on a conversion factor of 1.42 pCi day^{-1} WL^{-1}, the geometric mean lung exposure derived from the ^{210}Pb excretion rates was estimated at 0.43 WL. This mean value differed substantially from the value of 0.14 WL estimated from the concentrations of radon and radon decay products reported to be in the atmospheres of the buildings in 1977[1].

Possible causes of the differences in the estimated exposures were presented. The breathing and retention rates may have been higher than

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†$F = \frac{D \cdot 100}{^{222}Rn \text{ conc.(pCi/L)}}$,
where D is the concentration of radon daughters in units of Working Level, and one WL is any combination of the short-lived radon decay products (^{218}Po, ^{214}Pb and ^{214}Bi) in one liter of air that will result in 1.3×10^5 MeV of potential alpha energy.

assumed for the model, as may have the urinary-to-fecal excretion ratio. Since the most significant source of ^{210}Pb appears to be the radon dissolved in the body fluids, adjustments upwards of the ratio of radon in the body relative to that in the air could substantially increase the conversion factor used to estimate the exposures.

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CONTINUED STUDIES OF THE GASTROINTESTINAL ABSORPTION OF PLUTONIUM BY RODENTS

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In the mouse the gastrointestinal absorption of hexavalent plutonium (the form present in chlorinated drinking water) is (1) a factor of about ten lower in the fed animal than in the fasted one (0.015 vs. 0.15%), (2) independent of plutonium concentration over a range that broadly brackets the MPC for plutonium in drinking water, and (3) independent of the time of day the solution is administered to fasted animals. Other factors related to the determination of G.I. absorption which have been investigated are: (1) the adsorption of plutonium onto teeth of animals during both gavage and ad libitum administrations, (2) the formation of polymeric tetravalent plutonium during and subsequent to solution preparation, and (3) the relationship between the metabolic behavior of plutonium solutions, administered both intragastrically and intravenously, and their ultrafilterability.

Introduction

To a major degree, the maximum permissible concentration (MPC) of plutonium in drinking water is based on the results of experiments by Katz et al.[1] and Weeks et al.[2] in which 0.01 M nitric acid solutions of Pu(IV) ranging in concentration from 10^{-12} to 10^{-6} g/mL were administered to rats for a protracted period. The values obtained for G.I. absorption were 0.002 to 0.003% of the amounts administered. Weeks et al. also reported a value of 2.3% when Pu(VI) rather than Pu(IV) was administered. Since Larsen and Oldham[3] had found that the form of plutonium in chlorinated drinking water is Pu(VI), we reinvestigated the effect of plutonium oxidation state on gastrointestinal absorption. The results that we have obtained, which have been reported in two previous Annual Reports,[4,5] were significantly different from those of the earlier investigators. In our first report,[4] the value reported for Pu(VI) was significantly lower than the value of Weeks et al. (0.17 vs. 2.3%), and the value for Pu(IV) was much higher than the values of Katz et al. and Weeks et al. (0.20 vs. 0.002 to 0.003%). The value obtained for Pu(IV) in citrate buffer was the only one not significantly different from those of earlier investigators.

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The possibility that plutonium absorption was dependent on the administration medium was investigated and the results were reported in the last Annual Report.[5] Our medium has been 0.01 M sodium bicarbonate containing either Pu(VI) (to simulate chlorinated drinking water) or Pu(IV) (to simulate untreated water), while that of other investigators has, almost exclusively, been 0.01 M HNO_3 containing Pu(IV). The value we obtained when the administration medium was 0.01 M nitric acid containing Pu(IV) was 0.20%, essentially the same as that obtained for 0.01 M sodium bicarbonate containing Pu(IV), 0.17%. The possibility that our significantly higher values for plutonium absorption were related to the species of animal, the mouse rather than the rat, was also investigated. When Pu(VI) in dilute bicarbonate solution was administered to the rat, the absorption value was 0.32%, (vs. 0.17% for the mouse), and when this solution was administered to the dog, the value was 0.066%.[6]

In the investigations of Katz et al.[1] and of Weeks et al.,[2] solutions of Pu(IV) that ranged in concentration from 1×10^{-12} to 1×10^{-6} g/mL and were 0.01 M in nitric acid were administered to groups of fed rats. The mice, rats, and dogs in our experiments were fasted. Since our absorption values were much higher than those of Weeks et al., it became apparent that an investigation of the effect of feeding regimen and a reinvestigation of the effect of plutonium concentration were warranted. One of our explanations for the 100-fold difference between their absorption values and ours has been that the plutonium in their solutions was polymeric rather than monomeric.

Other factors investigated were: (1) the relationship between the time of day solutions are administered and G.I. absorption, (2) the adsorption of plutonium onto the teeth of mice during their ad libitum consumption of both Pu(IV) and Pu(VI) bicarbonate solutions, (3) an apparent relationship between the absorption of plutonium and the ultrafilterability of the administered solution, and (4) the polymerization of Pu(IV) in 0.01 M nitric acid when the plutonium concentration is 1×10^{-6} M, the highest concentration used in the study by Weeks et al. of plutonium absorption in fed animals.

General Experimental

In these experiments, solutions of Pu(IV) in 0.01 M sodium bicarbonate, Pu(VI) in 0.01 M sodium bicarbonate, and Pu(IV) in 0.01 M nitric acid were administered to groups of mice. The procedures used to prepare these

solutions and the methods of administration were the same as those reported previously.[4,5] Unless otherwise stated, the plutonium concentrations were approximately 1 x 10^{-10} M and the number of animals in each experiment was 10. The methods of administration and other experimental conditions are presented in the individual sections below.

Effect of Feeding Regimen

The effect of feeding on the absorption of plutonium was established by administering a solution of $^{236}Pu(VI)$ in a 0.01 M bicarbonate medium (via drinking tubes) to two groups of mice. The administration was from 5 p.m. to 9 a.m. (during their active phase). One group was fasted from 8 hr before to 8 hr after the administration period, while the other group was allowed to feed ad libitum before, during, and after the administration period. After six days, the mice were sacrificed, skinned and eviscerated; the heads were removed from the eviscerated bodies, and the livers and headless bodies were analyzed for ^{236}Pu. From the amount of plutonium in the headless carcass, the amount of plutonium in the total skeleton was calculated. This calculation was based on the data for skeletal distribution of plutonium reported in the following paper of this report.

The fractional absorption of plutonium in the fasted mice was 0.13 ± 0.02%, while that in the fed mice was 0.015 ± 0.001%. This decrease, by a factor of 9, between the fasted and the fed states is in general agreement with data reported by Sullivan et al.[7] In their study (of the effect of oxidation state), a solution, 2 x 10^{-3} M in $^{239}Pu(VI)$ and 0.01 M in nitric acid, was administered to both fasted and fed rats. The absorption value obtained for the fasted animals was 0.45%, while that obtained for the fed animals was 0.024%, the decrease being a factor of about 20. Similarly, Stather et al.[8] administered Pu(VI) in bicarbonate solution to fasted and fed hamsters, and obtained absorption values of 0.011 and 0.0022%, respectively. There is some question, however, about their value for the fasted animals in that feeding was restored immediately after the plutonium was administered. It should be noted that their value for the fasted hamster is a factor of 8 lower than our value for the fasted mouse and a factor of 22 lower than the value of Sullivan et al. for the fasted rat.

The most recent value adopted by the ICRP[9] for the fraction of soluble plutonium transferred from the G.I. tract to blood in man is 1 x 10^{-4} (an

increase of a factor of 3 since our investigation began). Considering the values we have obtained in animals, it appears that the value for man should be reviewed. The effect of feeding is particularly important since the consumptions of drinking water and of food by man are not necessarily concurrent.

Plutonium Concentration

The possibility that plutonium absorption was dependent on plutonium concentration was investigated by supplying Pu(VI) bicarbonate solutions ad libitum to fed mice during their active phase. The concentration range investigated was 1×10^{-12} to 1×10^{-8} M, from a factor of 30 less to a factor of 300 higher than the MPC for ^{239}Pu in drinking water (a solution of ^{239}Pu that is 3×10^{-11} M corresponds to an activity concentration of 5 pCi/mL). Three solutions were administered to three groups of 8 mice, A, B, and C. They received a 1.0×10^{-12} M solution of ^{236}Pu on day 0, a 1.4×10^{-10} M solution of ^{238}Pu on day 7 and a 1.1×10^{-8} M solution of ^{239}Pu on day 14. Groups A, B, and C were sacrificed on days 21, 28, and 35, respectively. The

Table 1. Design of the experiment to establish the effect of plutonium concentration on its G.I. absorption in fed mice.

Admin. day	Plutonium Isotope	Plutonium Molarity x 10^{12}	Group	Sacrifice day	Postadmin. time, days
0	236	1.0	A	21	21
			B	28	28
			C	35	35
7	238	140.0	A	21	14
			B	28	21
			C	35	28
14	239	11,000.0	A	21	7
			B	28	14
			C	35	21

experimental design is summarized in Table 1. The livers of the mice were analyzed by alpha spectrometric isotope dilution (ASID), using ^{242}Pu as the isotopic diluent. Since three plutonium isotopes had been administered, each analysis provided a value for the amount of each isotope in that liver at the

time of sacrifice.

The results obtained in this experiment are summarized in Table 2. Since other investigators have shown that the retention of plutonium in the liver of the mouse decreases quite rapidly with time after I.V. injection, the effect of plutonium concentration on the G.I. absorption was established by a

Table 2. Effect of plutonium concentration on G.I. absorption in fed mice.

Postadmin. time, days	Plutonium molarity x 10^{12}	Retention in liver, % x 10^{4}
7	11,000.0	86 ± 16
14	140.0	72 ± 16
14	11,000.0	92 ± 12
21	1.0	40 ± 7
21	140.0	59 ± 7
21	11,000.0	58 ± 5
28	1.0	37 ± 6
28	140.0	38 ± 6
35	1.0	24 ± 3

comparison of the liver retention values that correspond to the same post administration time. (Our data confirm the decrease in liver retention with time.) From the agreements in the values obtained for plutonium retention at 14, 21, and 28 days, it is apparent that plutonium absorption is independent of its concentration in the administered solution over a concentration range that brackets the MPC for plutonium in drinking water.

Activity Phase of the Animal

It has been observed that the absorption of cadmium in fasted mice[10] is a factor of about two higher during their active phase (during the night when they feed) than during their inactive phase (during the day when they sleep). Since plutonium administrations had been made to animals during their inactive phase in our previous investigations, the effect of the activity phase of the animal was investigated. A solution of Pu(VI) in 0.01 M sodium bicarbonate was supplied ad libitum to fasted mice, one group during their

active state (introduced at 5 p.m. and removed at 9 a.m.) and the other group during their inactive phase (introduced at 9 a.m. and removed at 5 p.m.). The mice were sacrificed after six days, they were skinned and eviscerated, the heads were removed and the headless bodies and livers were analyzed. From the value obtained for the amount of plutonium in the headless carcass, the amount in the total skeleton was calculated. This calculation is based on the data for skeletal distribution of plutonium reported in the following paper. The fraction of plutonium retained (skeleton plus liver) after administration to fasted mice during their active phase was 0.13 ± 0.02%. Following administration during their inactive phase, it was 0.17 ± 0.03%. Apparently, the absorption of plutonium ingested when the mouse is in the active phase is not significantly different from the corresponding absorption for the inactive phase.

Tooth Contamination

In the course of an investigation of cadmium and lead absorption in mice being carried out by one of us (M.H.B.),[11] it was discovered that the values obtained were significantly higher when the method of administration was ad libitum than those obtained when the method of administration was gavage. A subsequent investigation showed that the cause for this was the adsorption of these elements onto the bony surfaces of the mouth.

Some of the animals from the plutonium concentration experiment (see preceding section) were used to establish whether or not plutonium behaved similarly. When the heads and headless bodies of skinned and eviscerated animals were analyzed separately, it was found that the ratios of the amounts of plutonium in the heads to those in the headless bodies were inordinately high. In one animal, the ratio was 7. When palates were analyzed, the amounts found were negligible relative to the amounts found in the heads. The results obtained in subsequent analyses of various parts of the heads (bony palate, nose, mandible, skull, and teeth) indicated that the excess plutonium was on or in the teeth.

It was established that the plutonium was on the exposed surfaces of the teeth, the enamel ends, presumably as the result of surface adsorption during the consumption of drinking water. Teeth were removed from mice that had been supplied a 10^{-6} M $^{239}Pu(IV)$ solution ad libitum (see following section) and these teeth were assayed in (1) an alpha spectrometer, (2) a flow proportional

counter with the enamel ends of the teeth embedded in heavy grease and (3) in a flow proportional counter with the root ends of the teeth embedded. The teeth were subsequently analyzed destructively by ASID. There was very little degradation of the peak in the alpha spectrum indicating that the plutonium was on a surface; the flow proportional counter assays showed that there was plutonium on the enamel ends but not on the root ends; the value obtained in the destructive assay was within a factor of two of that obtained in the flow proportional counter assay with the enamel ends exposed. In a subsequent experiment, it was demonstrated that Pu(VI) is also adsorbed. The ease and rapidity of adsorption were demonstrated by an experiment in which the teeth (about 50 mg) from a mouse were immersed in 50 ml of a 0.01 M bicarbonate solution of ^{237}Pu(VI). The solution was swirled occasionally. After 5 hr, 15% of the plutonium was on the teeth.

Contamination of the teeth during ad libitum consumption of plutonium cast some doubt on the values that have been reported for plutonium absorption, when the administration method was by gavage.[5] If in this operation as little as 0.1% of the administered solution had inadvertently contacted the teeth and been adsorbed, the error in the G.I. absorption values would have been large. That this had not happened in the gavage experiments is suggested strongly by the comparison that was made of the ratios of the plutonium contents of liver and skeleton. No one of these ratios was appreciably lower than the others.

Nevertheless, an experiment was performed to establish the degree of tooth contamination during gavage administration of both Pu(IV) and Pu(VI) bicarbonate solutions to mice. The mice were sacrificed on day 6, they were skinned and eviscerated, and the heads were removed from the eviscerated bodies. The lungs, livers, headless bodies, and heads from three mice given the Pu(IV) solution and from nine mice given the Pu(VI) solution were analyzed. (The analysis of lungs prior to any other analysis is standard practice in our investigations when administration is by gavage. It is done to ensure that plutonium incorporation in the animal did not occur via the lungs.) In three of the Pu(VI) mice, there were significant amounts of plutonium in both the lungs and the heads. In the six other Pu(VI) mice, the ratio of the value for the head to that for the headless body ranged from 0.19 to 1.1 with the mean of the five lowest being 0.27. In the three Pu(IV) mice, there was no lung contamination and the ratio of the value for the head to

that for the headless body ranged from 0.21 to 0.25. The ratio of the values for the head and for the headless body obtained when Pu(IV) bicarbonate, Pu(VI) bicarbonate, and Pu(IV) citrate solutions were injected intravenously were all 0.17 (see the following paper in this report). It is thus apparent that in experiments where the administration method was gavage and tooth contamination may have affected the measured skeletal burden, the frequency with which this occurred was low. When coupled with the comparison of liver to body ratios cited above, and with the standard practice of discarding occasional statistical outliers, this finding strongly suggests that the absorption values reported previously are not in error due to a tooth contamination problem.

The value obtained for the G.I. absorption of Pu(VI) in this investigation of tooth contamination was 0.18 ± 0.05%. The amount of plutonium in the skeleton was established by multiplying the amount in the headless body by 1.20 (see the following paper), the amounts in the skeleton and liver were summed, and the sum was divided by the amount administered. The value reported previously for Pu(VI) absorption was 0.15 ± 0.03%.

Ultrafilterability of Plutonium Solutions and G.I. Absorption

The solutions of plutonium in 0.01 M bicarbonate that have been prepared and used in the course of this investigation have all been tested for their ultrafilterability (UF), the percent of plutonium that passes through the dialysis tubing, not the percent retained by it. The method used was that of Lindenbaum and Westfall.[12] Duplicate tests were performed on each solution; the relative difference in the pairs of values was in all cases 10% or less.

The UF of the ten Pu(VI) solutions that have been prepared has ranged from 70 to 98% with the average being 85%. Since the percentage of Pu(VI) in these solutions has ranged from 92 to 99%, it is difficult to see why the ultrafilterability could be as low as 70%. Pu(IV) is subject to polymerization, and hence could have a low UF. Pu(VI) is not subject to polymerization. There has been no correlation between percent Pu(VI) and percent UF. For three solutions having Pu(VI) percentages greater than 97%, the UF values ranged from 80 to 99%. There has been no correlation between these UF values and G.I. absorption.

A correlation has been observed between the UF of Pu(IV) bicarbonate solutions and the values obtained for G.I. absorption. The UF values for

three of the seven Pu(IV) solutions that have been prepared were greater than 70%, and the values obtained for G.I. absorption using these solutions have not been significantly different from those for Pu(VI) solutions. The UF values for the other Pu(IV) solutions were less than 25%, and the values obtained for G.I. absorption have been much lower than those for both the Pu(IV) solutions having high UF values and the Pu(VI) solutions. The fractional absorption of Pu(IV) for a solution with a UF of 10% was 0.037 (administered to fasted mice during their active state). In identical experiments, one where the UF of a Pu(IV) solution was 70%, and the other where the UF of a Pu(VI) solution was 85%, the fractional absorptions were 0.20 and 0.15%, respectively. We have no explanation for the differences in the UF values of the Pu(IV) solutions since particular care has been taken in this investigation to prepare all solutions of a particular type in exactly the same way.

The tentative conclusions we have drawn about Pu(IV) bicarbonate solutions with low values of UF are that (1) a significant fraction of the plutonium in these solutions was polymeric, and (2) the G.I. absorption of this form of plutonium is much lower than that of monomeric plutonium. In this case "monomeric plutonium" is operationally defined. It is the percent plutonium that passes through the dialysis tubing used in the test. (All the absorption values we have reported previously have been for animals that were administered solutions having UF values of 70% or more.)

The observation that the UF of Pu(IV) solutions and G.I. absorption are correlated is important in that it demonstrates clearly the need to characterize Pu(IV) solutions prior to their administration to animals in metabolic studies. In view of the very low concentration of plutonium in our solutions (about 1×10^{-10} M) we had considered the possibility of polymer formation to be very remote, particularly when such complexing agents as bicarbonate, and carbonate (due to the dissociation of bicarbonate) were known to be present. We had continued to perform the ultrafilterability test because it had been standard practice when using plutonium solutions of much higher concentrations (in other metabolic studies), and the test was a relatively easy one to carry out.

A test in which animals would be used to characterize Pu(IV) solution is being considered. One method which would be easy to perform and which shows considerable promise is an intravenous injection followed by an analysis of

the liver and carcass. Six days after the intravenous injection to three mice of a Pu(VI) bicarbonate solution having a UF of 99%, the liver to carcass ratio was 0.41 ± 0.01, and in eight mice that were administered this solution intragastrically by gavage, the ratio was 0.40 ± 0.02. When the solution was a Pu(IV) bicarbonate solution having a UF of 10%, the value for the ratio in three mice that had had intravenous injections was 4.32 ± 0.16, and in six mice that had had intragastric administrations, it was 0.52 ± 0.07. The high value for the ratio of liver to carcass obtained for the Pu(IV) solution administered intravenously is consistent with the observations of many other investigators, to wit, polymeric plutonium deposits in the liver.

Polymerization of Pu(IV) in 0.01 M Nitric Acid

An explanation we have offered[4] for the significant difference that exists between our value for the G.I. absorption of Pu(IV) in the fasted mouse (about 0.20%) and those of the earlier investigators (about 0.003%) has been that the plutonium in their solutions became polymerized either during preparation or during the protracted administration period. Very significant changes in the optical absorption spectrum of a 1×10^{-3} M Pu(IV), 0.1 M nitric acid solution have been observed by Ockenden and Welch[13] within an hour of preparation. In the investigation by Weeks et al.[2] of plutonium absorption by fed rats, the concentrations of Pu(IV) in the 0.01 M nitric acid solutions used ranged from 10^{-12} to 10^{-6} M.

An investigation of the changes with time that may have occurred in their solutions was therefore undertaken. The solution used was 1×10^{-6} M Pu(IV), 0.01 M nitric acid. It was prepared by evaporating a portion of a 6 M nitric acid stock solution of ^{239}Pu to incipient dryness (nitric acid fumes were still present), adding 1.00 ml of 1 M nitric acid, and diluting the solution to 100 ml with water. The solution was administered to groups of fed mice (five per group) at various times after its preparation: 0, 3, 9, 30, and 217 days. Six days after each administatration, the fractional retention of plutonium in the livers was determined. The ultrafilterability of the solution and the oxidation states of the plutonium were also determined on each of the days the solution was administered.

The results of this study are presented in Table 3. A comparison of the values for liver retention with that obtained for a 1×10^{-8} M Pu(VI) bicarbonate solution, 86 ± 16 $\times 10^{-4}$%, (see Table 2) shows that this plutonium

was not absorbed as readily. Nevertheless, the absorption of this plutonium after day zero was greater than the values obtained by Weeks et al. The liver

Table 3. Changes with time of the properties (G.I. absorption, ultrafilterability and oxidation state) of a 1 x 10^{-6} M Pu(IV), 0.01 M nitric acid solution.

Time of admin. days after preparation	Retention in liver, % x 10^4	Ultrafilter-ability, %	Oxidation state, %[a] IV	VI
Zero	16 ± 4	55	98	3
3	32 ± 1	39	92	8
9	31 ± 1	72	85	15
30	32 ± 2	68	74	25
217	46 ± 5	87	50	48

[a] Determined by the lanthanum fluoride precipitation procedure.

values for solution ages of 3, 9, and 30 days correspond to a G.I. absorption value (carcass plus liver) of 0.009% and on day 217 to a value of 0.013%. Due to the oxidation of Pu(IV) to Pu(VI) that occurred (by atmospheric oxygen, or possibly nitrite), the UF values on day 3 and after are not those for Pu(IV); they are for a solution containing both Pu(IV) and Pu(VI). If one assumes that the UF of the Pu(VI) in the solutions was 100%, then the UF's of the Pu(IV) in the solutions were 55, 39, 66, 57, and 75% for ages 0, 3, 9, 30 and 217 days, respectively. This is not the result that we had expected: we had expected that the plutonium would polymerize, i.e., the UF of the solution would decrease with time due to the polymerization of Pu(IV).

The conclusions that can be drawn from the results of this experiment are that (1) Pu(IV) solutions that are 1 x 10^{-6} M in plutonium and lower do not polymerize with time when the medium is 0.01 M nitric acid and (2) Pu(IV) in 0.01 M nitric acid solutions is slowly oxidized to Pu(VI). The values for the G.I. absorption of plutonium reported by Weeks et al.[2] (the ones used to establish a value for man) were obtained using solutions that were 10^{-12} to 10^{-6} M in Pu(IV) and 0.01 M in nitric acid. They were administered to fed rats for several hundred days. Since the values they obtained were 0.002 to 0.003% and our values for 3- to 217-day-old solutions ranged from 0.009% to 0.013%, the conclusion is drawn that the plutonium in the two solutions used to prepare the solutions they administered was polymeric. (The geometric

progression of the concentrations used in their experiments suggests strongly that there were just two stock solutions and that they were diluted with 0.01 M nitric acid to obtain the solutions administered.)

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DISTRIBUTION OF PLUTONIUM IN THE MOUSE SKELETON - A STUDY OF EFFECTS DUE TO CHEMICAL FORM AND MODE OF ADMINISTRATION

R. P. Larsen, R. D. Oldham and M. C. Engel*

A study has been made of several factors that might affect the distribution of plutonium within the skeleton: the oxidation state of plutonium in intravenously injected solutions, the nature of the medium used to administer plutonium intravenously, and the mode of entry into the blood (intravenous injection vs. gastrointestinal absorption). The distributions of intravenously injected Pu(IV) and Pu(VI) were the same, the distribution of intravenously injected Pu(IV) bicarbonate solution was the same as that for a Pu(IV) citrate buffer solution and the distribution of plutonium absorbed from the G.I. tract was the same as those obtained subsequent to intravenous injection. For a Pu(VI) bicarbonate solution that was injected either intravenously or intragastrically, the deposition in liver was somewhat lower than that for a Pu(VI) citrate buffer solution injected intravenously.

Introduction

In most studies that have been made of the metabolic behavior of plutonium in mammals, citrate buffer has been the medium chosen for its administration. There are several reasons for this: (1) there has been general agreement that the oxidation state of plutonium in these systems is IV, (2) inorganic Pu(IV) compounds and in particular the hydroxide are very insoluble at pH 3 and above, (3) Pu(IV) is strongly complexed by citrate and the complexes are soluble even at pH 7, (4) the solution must be biologically compatible, and (5) the amount administered must be such that concentrations can be measured in those tissues where the relative deposition (percent of dose/percent of body weight) is as low as 0.05. For intravenous injections the amount of ^{239}Pu must be 15 μg (~1 μCi) if the weight of tissue is one gram, the weight of the animal is 1000 g, the desired accuracy of the measurement is ± 10% (R.S.D.), and the counting time in the analysis is 100 minutes. If the volume of solution administered is 1.0 ml, the molar concentration must be about 1×10^{-4}, a concentration that cannot be maintained even in 0.01 M nitric acid in the absence of a complexing agent. (At plutonium and nitric acid concentrations of 4×10^{-3} M and 0.1 M, respectively, about 50% of the plutonium is polymerized in an hour.[1]) If the

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solution is administered intragastrically, the concentration must, of course, be much higher.

The information available on the metabolic behavior of plutonium that gets into the blood is based to a large extent on the results of experiments in which Pu(IV) citrate was injected intravenously. An example is that of the human injection cases, one aspect of which is presented in the paper that follows in this report. There is a tacit assumption that our reported distributions of plutonium within the skeleton would have been the same had the plutonium been administered as a soluble constituent of drinking water rather than injected intravenously as the citrate complex. Since this chemical form of plutonium is surely quite different from that which enters the blood from the G.I. tract (and the lungs), it appeared that a comparison should be made between the behavior of plutonium injected intravenously as the citrate complex, i.e., distribution within the skeleton and amongst important tissues, with the behavior of plutonium that was injected in some other chemical form and absorbed from the G.I. tract. The possibility existed that the citrate complex of Pu(IV) was more stable than the transferrin complex (the form in which plutonium exists ordinarily in the blood) and/or that the rate of reaction between the citrate complex and transferrin was slow. If either of these was the case, the reported distribution among the tissues and within the skeleton was for the citrate complex; this might not be the same as those for the transferrin complex. A very practical problem that existed if the distribution of the two forms within the skeleton was not the same, was that of establishing the skeletal burden. This is frequently done by determining the amount in the femur and multiplying this value by the skeleton to femur activity ratio that was obtained in citrate injection experiments. Although it appeared that the probability of there being a difference was small, the consequences to the general understanding of the metabolic behavior of plutonium would be large, should there be such differences. Hence this investigation was undertaken.

We have also had some doubt about the validity of the premise that plutonium in blood is in the IV state. In natural waters that have low concentrations of dissolved organic carbon (0.1 to 1 ppm) the dissolved plutonium (from fallout) is primarily in the V state, while in those waters having high concentrations of dissolved organic carbon (5 to 10 ppm) the plutonium is primarily in the IV state.[2] It has also been demonstrated that

this organic carbon complexes plutonium very strongly. In blood the concentration of oxygen (the reagent responsible for the oxidation of Pu(IV) to Pu(V)) is significantly higher than it is in natural water, but the concentrations of both the ligands that complex Pu(IV) and the reactants that could reduce Pu(V) to Pu(IV) are presumably much higher than they are in natural water. The latter components would have the effect of shifting the Pu(IV)-Pu(V) redox couple in the direction of the IV state. Considering all these factors, it is apparent that the plutonium redox situation in blood is very complex and that establishing what the oxidation state(s) is(are) would be very difficult if an attempt were made to determine it(them) directly.

Experimental

Solutions that were 2×10^{-10} M $^{236}Pu(IV)$ and 5×10^{-8} M $^{238}Pu(VI)$ and both 0.01 M in sodium bicarbonate were administered intravenously to separate groups of three fed mice, and a 1×10^{-9} M $^{237}Pu(VI)$ solution was administered intragastrically (ad libitum) to a group of six fasted mice. After six days the mice were sacrificed, skinned, and eviscerated and the carcasses dissected to obtain various individual bones and bone groups. The bone samples and livers that contained ^{236}Pu and ^{238}Pu were analyzed by alpha spectrometric-isotopic dilution, while those that contained ^{237}Pu were analyzed (nondestructively) by counting the Np K x ray emitted in its decay. The bones in the heads of the mice that were administered plutonium intragastrically were not assayed because of possible tooth contamination. (See the preceding paper in this report.) The methods used to prepare these solutions have been described previously.

Results and Discussion

The relative concentrations of plutonium in the skeletal bones of the mice that were injected intravenously with Pu(IV) and Pu(VI) bicarbonate solutions are given in Table 1 and are compared with the values obtained by Rosenthal et al.[3] for a 1.5×10^{-5} M $^{239}Pu(IV)$ citrate solution. It is apparent from these data that the pattern of plutonium deposition in the skeleton is independent of the chemical form of the plutonium at the time it enters the blood. It would appear that the several forms of plutonium that were injected intravenously and the plutonium transferred from the G.I. tract to blood are very probably converted to a common form in the blood prior to

Table 1. Influence of oxidation state, administration medium, and mode of administration on the distribution of plutonium in the skeleton of the mouse

Bone or bone group	Percent of skeletal plutonium after intravenous injection of				G.I. absorption of	
	Pu(IV) citrate[a]	Pu(IV) HCO_3[b]		Pu(VI) HCO_3[b]		Pu(VI) HCO_3[b]
Cranial group[c]	15.4[d]	14.7[d]	(1.0)	16.5[d]	(1.0)	- -
(head w/out teeth)	-	13.8	-	15.1	-	- -
(teeth)	-	0.8±0.2	-	1.4	-	- -
Ribs, vertebral	6.2	4.2	(0.7)	4.6	(0.7)	4.4[c] (0.8)
Ribs, sternal	0.7	0.6	(0.6)	0.7	(0.7)	0.6 (0.8)
Sternum	2.3	2.2	(1.1)	2.1	(0.8)	1.8 (0.7)
Misc. group[c]	12.8	12.6	(1.0)	11.9	(1.0)	10.0 (0.9)
(clavicula)	0.5	-	-	0.1	(0.2)	0.5 (0.8)
(scapulae)	3.0	-	-	2.7	(0.7)	2.6 (0.6)
(tail)	9.3	-	-	9.1	(1.1)	7.6 (1.0)
Appendicular group[c]	12.0	14.6	(1.1)	11.5	(0.9)	12.2 (1.1)
(humeri)	4.2	-	-	3.5	(0.8)	4.9 (1.1)
(radii/ulnae)	1.9	-	-	1.3	(0.6)	1.6 (0.9)
(tibiae/fibulae)	5.9	-	-	6.6	(0.9)	5.7 (1.0)
Femora	8.2	8.9	(1.1)	8.7	(0.9)	8.2 (1.1)
Vertebral group[c]	32.0	34.3	(1.0)	36.5	(1.0)	35.0 (1.1)
(cervical)	4.0	-	-	4.9	(0.9)	4.8 (1.1)
(thoracic)	9.7	-	-	11.1	(1.1)	9.8 (1.1)
(lumbar)	11.4	-	-	12.3	(1.1)	13.2 (1.2)
(sacral)	6.9	-	-	8.1	(1.0)	6.9 (1.0)
Pelvis	6.8	7.8	(1.1)	7.5	(1.0)	7.7 (1.1)

[a] Data from Rosenthal et al. [3]
[b] Values in parentheses are relative to Pu(IV) citrate injection.
[c] These values are sums of the group components.
[d] For percentages greater than 5, relative errors are ± 10%. For percentages less than 5, relative errors are ± 25%.

deposition on bone surface. In the matter of oxidation state, it cannot be concluded from these results which one is present in blood. It can be concluded, however, that if the stable form in blood is Pu(V), the rate of either the reduction of Pu(VI) to Pu(V) or the oxidation of Pu(IV) to Pu(V) is rapid. If the stable form in blood is Pu(IV), the rate of reduction of Pu(VI) to Pu(IV) is rapid.

There is some question about the use of citrate media, however, in establishing the deposition pattern of plutonium among the tissues. Rosenthal et al. obtained a liver-to-skeleton ratio of 0.75. In the course of this experiment and others, eight different Pu(VI) bicarbonate solutions have been administered both intravenously and intragastrically to mice. The mean of the liver-to-skeleton ratios was 0.52, with a range of 0.41 to 0.68. In a comparison of Rosenthal's value with these, it should be noted that there was a significant difference in the amounts of plutonium that were administered

intravenously. In their experiments it was 3.6 μg, while in ours it was 5×10^{-5} μg for ^{236}Pu and 1.2×10^{-2} μg for ^{238}Pu.

The results obtained in this investigation indicate that the distributions of plutonium within the skeleton that have been obtained in experiments where plutonium was injected intravenously as the citrate complex are applicable to the interpretation of skeletal distributions obtained in experiments where there was a different mode of entry and/or the plutonium was in a different chemical form. Some question remains about the distribution among tissues. The difference between the liver-to-skeleton ratio after a citrate injection and the ratio after gastrointestinal absorption suggests that the conversion of the citrate complex of plutonium to the "normal" form of plutonium in blood is not instantaneous.

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DISTRIBUTION OF PLUTONIUM IN THE HUMAN SKELETON - A COMPARISON OF TWO INJECTION CASES

R. P. Larsen and R. D. Oldham

The macrodistribution of plutonium in the skeleton of an older man who received ^{239}Pu by injection has been established and has been compared with that in the skeleton of a young woman. The data show that the patterns of distribution are very similar, but the range of concentration between the bones having the lowest and highest concentrations is a factor of about two lower in the man than it is in the woman. Possible reasons for this difference are given.

Introduction

An investigation is being carried out to establish the burden and macrodistribution of plutonium in the skeletal remains of a 65-year-old man who received 0.38 μCi by injection in 1945, and who succumbed to his pre-existing illness about 500 days later. These results are being compared with those obtained for a 20-year-old woman who received a comparable amount of plutonium and who also succumbed to her illness about 500 days later. The dissimilarities of these two cases are age, sex, and the nature of their illnesses. Preliminary results obtained in the investigation of the man's remains have been reported,[1] as have the results of the detailed investigation of plutonium distribution in the woman's skeleton.[2] Information on the condition of their remains at the times of exhumation, methods of sampling and the analytical methodology are presented in those reports. These subjects who were referred to in the earlier literature as HP-9 and HP-4, respectively, have been assigned the CHR case numbers 40-015 and 40-010, respectively.

Results and Discussion

The distribution of plutonium in the bones of 40-015 is presented in Table 1 and is compared with that for 40-010. In each case the value for a particular bone, bone section, or bone group is the plutonium concentration in that sample (per gram ash) divided by the concentration in the tibia midshaft. (Within this group of samples the concentration in the tibia midshaft was in both cases lower than that in any other sample.)

It is apparent from the pattern of values in Column 3, the ratios of relative concentrations in the two skeletons, that the general distribution of plutonium in the two skeletons was quite similar. There are, however, several

Table 1. Skeletal Distribution of Injected Plutonium

Bone	Concentration relative to tibia shaft		
	Case 40-010 A	Case 40-015 B	A/B
Tibia, shaft	(1.00)	(1.00)	(1.0)
Radius, shaft	1.3	1.3	1.0
Ulna, shaft	1.3	1.2	1.1
Fibula, shaft	1.4	1.3	1.1
Humerus, shaft	2.2	1.6	1.4
Femur, shaft	2.3	1.4	1.6
Tibia, distal condyles	2.3	2.1	1.1
Ulna, condyles	2.5	2.1	1.2
Femur, condyles	2.8	2.1	1.3
Tarsals	3.2	1.8	1.8
Fibula, ends	3.4	2.6	1.3
Tibia, proximal condyles	3.9	2.6	1.5
Humerus, proximal condyles	6.4	4.2	1.5
Humerus, head	9.0	4.3	2.1
Scapula	21	8.9	2.4
Rib 2	23	15[a]	1.5
Rib 1	25	15	1.7
Rib 8	25	13[a]	1.9
Femur, head	25(8.9)[b]	3.1	8.1(2.9)
Rib 10	26	27	0.96
Rib 9	27	31	0.87
Vertebra, thoracic processes	37	16	2.3
Iliac crest	39	20	2.0
Sacrum	39	20	2.0
Vertebra, thoracic body	52	45	1.2
Vertebra, cervical body	57	29	2.0
Sternum	57	27	2.1
Manubrium and Sternum	59	28	2.1

[a]These values are known to be low by a factor of 1.5 to 2. They are for a section of rib.

[b]Values in parenthesis are for the other femur.

differences: (1) the concentrations of plutonium in the ribs of 40-010 are, for some unknown reason, relatively lower than those in the ribs of 40-015 and (2) the concentrations in the femur heads of 40-010 appear to be much higher than those in 40-015.

Although the distribution patterns in the two cases are similar, there is an obvious difference in the ranges of relative concentrations: the range in 40-010 is a factor of about two higher than that in 40-015. In any explanation for this difference, it appears that the distribution in the skeleton of 40-015 should be considered to be the more nearly "normal" of the two. As a consequence of age (20), the skeleton of 40-010 may still have been metabolically active, and a symptom of her illness (Cushing's syndrome) is osteoporosis. If the skeleton was metabolically active, the most active bones would be those that are predominantly cancellous, such as vertebra. Hence the amounts of plutonium deposited in these bones relative to the amount deposited in a highly cortical bone, such as the shaft of the tibia, would be greater in 40-010 than in 40-015. If osteoporosis had been occurring in 40-010, the loss of calcium in the highly cancellous bones would have been greater than that in the cortical bones and hence the increase in plutonium concentration with time would be expected to be highest in the cancellous bones. A premise for the latter is, of course, that calcium was lost from these bones more readily than plutonium.

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THE CONCENTRATION OF PLUTONIUM IN HAIR FOLLOWING INTRAVENOUS INJECTION*

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The concentration of plutonium has been determined along the length of the hair of a female subject who received 11 kBq (0.3 μCi) of ^{239}Pu by intravenous injection in 1945. The subject succumbed to her pre-existing illnesses 518 days post injection, and her remains were exhumed in 1973.

The subject's hair, 280 mm in length for the longest strands, was divided into 20-mm long sections, and the plutonium concentration in each was determined. The concentration ranged from 22 Bq/kg (0.59 pCi/g) at the distal end to 3 Bq/kg (0.08 pCi/g) at the proximal end (nearest the scalp). The distance of each section from the scalp was then converted to an estimated time in days post injection by applying the growth rate of the hair indicated for this individual.

The plutonium concentration as a function of time could be well fitted (in the least-squares sense) by either of two functions. The first function was the sum of a single exponential, whose half-time was 81 ± 16 days, plus a constant term. This half-time corresponded to that found for the longest-lived of five components of the plutonium concentration in the blood of other individuals in the same series of injections, i.e. 88 ± 13 days.[1] The second function which fitted the hair data was the sum of two exponentials whose half-times were 32 ± 18 and 260 ± 80 days, respectively. These values overlap the half-times of 42 and 300 days found for components of the urinary excretion of plutonium by man.[1] This agreement is expected in view of the correspondence of the hair and blood data, since urine is a plasma filtrate. The possible use of hair as a bioassay material for plutonium in man is suggested.

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RECALIBRATION OF THE ^{226}Ra EMANATION ANALYSIS SYSTEM

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The ^{226}Ra emanation system was found to require recalibration. The gain of the various counting systems was established to about ± 0.5%. The variance introduced into the analysis by multiple counting systems was low and corresponded to a fractional standard deviation of ± 0.5%. The variance introduced into the analysis by both multiple counting systems and multiple counting chambers needs to be redetermined but is less than a fractional standard deviation of ± 2%. The newly established calibration factor of 5.66 cpm/pg ^{226}Ra is about 6% greater than that used previously. The leakage of radon into the greased fittings of the emanation flask which was indicated in an earlier study was not confirmed.

Introduction

The ^{226}Ra emanation analysis system which has been in use since 1956 was found to produce results which were not within normal statistical limits. An investigation revealed that many of the counting units were new and the operating conditions had not been established by the method previously developed. An error in efficiency was also indicated. This report summarizes the method used to recalibrate and standardize the Argonne emanation analysis system.

The Counting System

The operating conditions for each unit in the counting system were established with a counting chamber, reserved for this purpose only, which was filled with helium and radon. A helium-filled chamber with ^{239}Pu (a long-lived alpha emitter) plated on the inside of the chamber window was calibrated against the radon-filled chamber. Either chamber may be used, although the ^{239}Pu chamber is preferred since it is always ready for use and the radon growth-decay corrections are not required.

The gain of each of the counting systems was standardized with the ^{239}Pu chamber by the use of an adjustable discriminator, and not from a high voltage plateau at a fixed discriminator setting. This was achieved by adjusting the discriminator to a setting (on our system) of 800, which corresponds to about 60% of the maximum amplifier output. Then the high voltage was adjusted until the count rate at this setting, 800, was 80% of that at a discriminator setting of 10. After correction of all counts for growth and decay, the high voltage on all other counting systems was adjusted with the discriminator at

800 until the correct counting rate was obtained. The variations in the gains of multiple systems calibrated by this method are within about ± 5%; on the other hand, when the high voltage plateau method is used, the gains may vary as much as factors of 2 to 4. An increase in gain by a factor of two increases the efficiency by 1.5%, while a decrease in gain by a factor of two reduces it by about 3%. The standard operating point is at a discriminator setting of 200, which is exactly one-fourth of that used to adjust the high voltage. Under these conditions, the discriminator rejects 3% and 6% of the counts in helium-and air-filled chambers, respectively.

Variance will be introduced into the results of analyses of ^{222}Rn (or of ^{226}Ra) because of small variations in the positioning of the chamber on the end of the photomultiplier tube and because of the non-uniformity of the various photocathodes. This effect was evaluated by counting a single alpha scintillation radon counting chamber in as many counting systems as possible. The results are summarized in Table 1. The mean fractional

Table 1. Variance introduced by multiple counting systems.

No. of counters	Mean total counts	Mean fractional standard deviation, %	
		Observed	Due to counting statistics
12	19,550	1.16	0.83
16	23,736	1.02	0.79
16	27,130	0.82	0.77
	Mean	0.97	0.80

standard deviation for each of the three sets of measurements ranged from 0.82 to 1.16% with a mean of 0.97%. The mean fractional counting error was 0.80%. If we assume that $\sigma^2_{obs} = \sigma^2_c + \sigma^2_I$, where σ^2_{obs} is the observed variance, σ^2_c is the variance estimated from the observed counts, and σ^2_I is the variance introduced by multiple counting systems, then this latter term corresponds to a fractional standard deviation of about ± 0.5%. If a more

precise estimate is required, then a more active sample and a larger number of counts are required.

The variance introduced into the analysis by using not only multiple counting systems, but multiple counting chambers as well was evaluated by filling sixteen chambers with air containing ^{222}Rn from a large compressed air cylinder containing emanating ^{226}Ra. Chambers were evacuated four at a time and filled at least three times using the radon transfer system.[1] These chambers were then counted for 100 min on each of six different counters. The results are summarized in Table 2.

Table 2. Relative efficiency of alpha scintillation counters when filled with radon in air.

Chamber No.	Mean activity, pCi	Mean normalized residual
4	26.52	1.92
5	26.40	1.68
16	26.39	1.48
21	25.21	-1.82
26	25.88	0.09
28	26.59	2.13
42	25.93	0.25
44	25.44	-1.08
45	26.69	2.32
46	25.74	-0.31
48	25.58	-0.63
49	25.50	-1.01
56	25.11	-1.97
61	24.77	-3.09
67	25.52	-0.87
69	25.65	-0.50
Mean	25.82	
Std. Dev.	0.48	

The chambers are grouped and listed in the order in which they were filled. The mean statistical counting error for each chamber was 1.43%. The normalized residual was calculated for each of the 96 measurements as the ratio of the deviation from the mean to the counting error. The mean activity and thus the mean normalized residual are seen to decrease systematically with each set of four chambers.

The significant decrease in the activity of each successive group of chambers suggests that the mean temperature of the air in the chambers was varying with time. Since adiabatic cooling during the initial system flush or heating of the rubber tubing in the transfer system with use are both involved, this experiment will have to be modified and repeated.

^{226}Ra Standardization

The system calibration factor for ^{226}Ra analysis was determined by the standard emanation method.[1,2] The results obtained are summarized in Table 3. The mean calibration factor of 5.66 cpm/pg ^{326}Ra is about 6% greater

Table 3. Measurements of ^{226}Ra in NBS standard samples.

Standard	Date	Activity, pg	No. of counters	Growth time, days	Calibration factor observed, cpm/pg
97-006	7/ 1/81	9.90	1	6.17	5.52
97-003	6/ 9/81	400.0	12	12.91	5.70
	6/16/81		16	7.04	5.74
	8/21/81		2	52.92	5.65
97-004	6/25/81	400.0	1	6.00	5.64
	8/26/81		1	48.92	5.63
	8/28/81		1	1.92	5.65
	8/31/81		1	2.99	5.70
	9/ 1/81		1	0.99	5.73
				Mean	5.66
				Std. Dev.	0.066

than that in use since about 1957. The results of extensive analyses of standards through 1977 suggest that this change should be applied to results only for the period January 1, 1978 to the present.

The stopcocks and ground glass joints on the emanation flasks are all sealed with grease in which radon may be dissolved. The loss or leakage of radon into the grease requires a modified equation for the growth of radon in the freshly de-emanated radium solution:

$$G = \frac{\lambda_R}{\lambda_R + \lambda_L} \left(1 - e^{-(\lambda_R + \lambda_L)t}\right),$$

where G = fraction of equilibrium attained during time, t, since the last de-emanation; λ_R and λ_L are the decay constant for ^{222}Rn and the fractional rate of the leak, respectively.

An estimate of λ_L of 1.1 ± 0.2%/day was obtained by non-linear least squares regression[3] of the data reported in an earlier study.[1] For values of t greater than 20 days, the value of G obtained is about 5% less than that from the usual growth equation. Since the precision of analysis is about ± 1%, this level of leak should be easily detected. However, when the data in Table 3 are analyzed as previously, λ_L = 0.03 ± 0.26%/day. This value is not significantly different from zero, and little leakage of radon into the grease of the emanation flasks is indicated. The amount (length) of greased seal varies considerably among the several emanation flask designs currently in use so that this study will be continued and extended.

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CALIBRATION OF A DECAY-PRODUCT COLLECTION AND COUNTING APPARATUS FOR THE DETERMINATION OF EXHALED THORON (^{220}Rn)

A. T. Keane and D. R. Brewster*

An apparatus for the electrostatic collection and subsequent alpha-particle counting of the decay products of thoron was calibrated for the determination of thoron in expired air. At seven experimental values of respiratory minute-volume ranging from 7.5 to 11.6 L, the overall efficiency of the apparatus averaged 0.50 ± 0.04 (S.D.). This efficiency is the product of the minute-volume dependent fraction of exhaled thoron atoms that decays in the 36 L collection chamber, the fraction of decay-product ions produced in the chamber that decays on the phosphor coating of the electrode disk (0.57), and the fractional efficiency of the alpha-scintillation counters (0.97).

Introduction

The apparatus for the determination of exhaled thoron (^{220}Rn) described by Aub et al.[1] was modified at the Radioactivity Center of the Massachusetts Institute of Technology to obtain improved efficiency in the determination of thoron in the expired air of radium workers.[2] A similar apparatus is in use here to determine thoron in the expired air of former thorium workers.[3-5] This paper describes the calibration of the apparatus and the method of measurement.

Method of Measurement

The determination of thoron activity outside the body is carried out by delivering exhaled air to a delay chamber where the positively-charged decay products of thoron are electrostatically collected. After a period of simultaneous breath sampling and decay-product collection, the active deposit on the collection electrode is measured in an alpha-scintillation counter.

The subject, fitted with a respiratory face mask connected to an expiration manifold, inhales medical-grade aged tank-air supplied through a respiration unit. Exhaled air flows through a tube connected to a collector head mounted on the expiration manifold into a cylindrical metal chamber of 36 L capacity (Figure 1). The chamber contains an insulated copper-disk electrode that is covered with a Mylar disk coated with zinc-sulfide phosphor. The subject exhales into the collection apparatus for about 7 min to bring the thoron content of the chamber to equilibrium before voltage is

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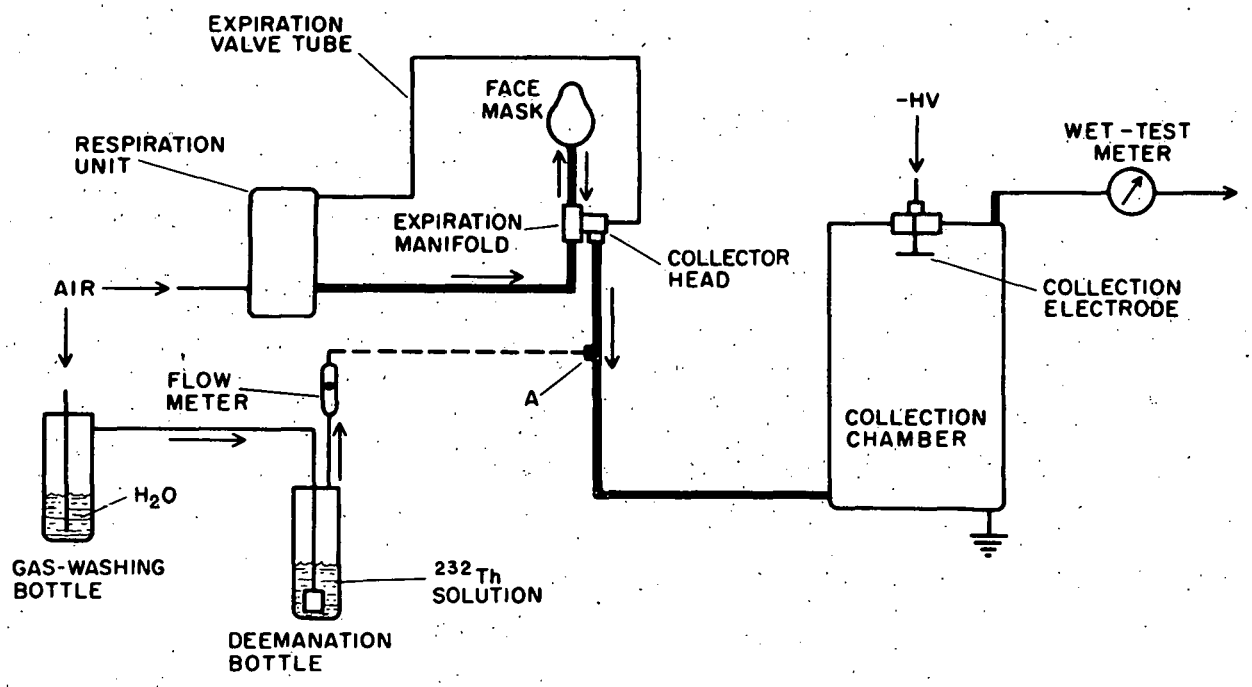

FIG. 1.--Diagram of the apparatus used in the collection of the decay products of exhaled thoron and the deemanation-apparatus used in the calibration experiments. The latter apparatus is connected to the former at point A. The 250 ml gas-washing bottle (03-036B, Fisher Scientific Co., Itasca, IL) contains 100 ml H_2O. The 250 ml deemanation bottle with fritted glass cylinder (03-040D, same supplier) contains old thorium nitrate dissolved in 100 ml 0.1 N nitric acid. The flow meter is of the float type (448-209-0018, Fisher and Porter Co., Warminster, PA). The Bennet Model PR-1 respiration unit, expiration manifold, and collector head were obtained from Inhalation Therapy Co., Chicago, IL. The stainless-steel collection chamber, 49.5 cm high and 30.5 cm in diameter, is similar in design to the smaller chamber described by Kuchta et al.[6] except that the intake and exhaust manifolds used in the smaller chamber are not present in the larger chamber. The phosphor-coated Mylar disks (15/16" Type AST-3, 4.35 mg ZnS cm^{-2} over 5 mil Mylar) were obtained from Wm. B. Johnson Co., Montville, NJ.

supplied to the electrode. The electrode is maintained 5.8 kV negative with respect to the walls of the chamber. Positively-charged ions of ^{216}Po (0.15 sec half-life) and especially of ^{212}Pb (10.6 hr half-life) produced from the decay of thoron (55 sec half-life) are collected on the phosphor. During the 50 min breath sampling period normally employed, the ^{212}Pb activity on the phosphor reaches 5.3% of its equilibrium value.

At the end of the period of breath sampling, the electrode is removed from the chamber and the collecting surface is presented to a second phosphor-coated Mylar disk in a Lucite holder. This is then placed on the window of a

photomultiplier for nearly 4-π counting of the alpha particles from ^{212}Pb daughters. The activity is usually counted for two or more ^{212}Pb half-lives. Initially, consecutive 10 min observations are made; after a few hours, the counting time for each observation is increased to 100 min. A weighted least-squares fit is carried out by computer of an equation that describes the growth and decay of the alpha-particle activity of the decay products of both radon (^{222}Rn, 3.8 day half-life), a normal contaminant, and thoron.

The results are expressed as thoron activity outside the body. This activity is equivalent to FX Bq ^{224}Ra (the parent of thoron) in the body, where X is the total ^{224}Ra activity in the body and F is the fraction of the thoron atoms produced in the body that is exhaled.

The electrode, the Lucite holder, the alpha-particle counters, and the analysis of the counting results have been described in detail by Kuchta et al.[6] The apparatus was calibrated by determining the overall efficiency, which is defined below, over a range of respiratory minute-volumes.

Efficiency

The overall efficiency E of the apparatus for the determination of exhaled thoron can be expressed as

$$E = f_\lambda \, f_C \, \eta \quad , \tag{1}$$

where f_λ is the fraction of exhaled thoron atoms that decays in the collection chamber, f_C is the fraction of the ^{212}Pb produced in the chamber that decays on the phosphor disk (collection efficiency), and η is the fractional counting efficiency.

If it is assumed that there is no mixing of incoming air with that already in the collection apparatus (smooth flow), the fraction f_S of exhaled thoron atoms that survives decay in the mask and the tubing leading from the mask to the inlet of the collection chamber and is delivered to the collection chamber is obtained from the equation of Evans,[7] i.e.,

$$f_S = e^{-\lambda v/R} \quad , \tag{2}$$

where λ is the radioactive decay constant of thoron (0.76 min^{-1}), v is the air

volume of the mask and the tubing leading from the mask to the chamber, and R is the flow rate.

The fraction f_D of thoron atoms delivered to the chamber that decays in the chamber is, from Evans,[7]

$$f_D = 1 - e^{-\lambda V/R} \quad , \tag{3}$$

where V is the volume of the collection chamber. The fraction f_λ is the product of f_S and f_D, so that, for smooth flow,

$$f_\lambda = e^{-\lambda v/R} - e^{-\lambda(v + V)/R} \quad . \tag{4}$$

On the other hand, if each increment of flow air is evenly dispersed in the collection apparatus (mixed flow), maintaining thoron at a uniform concentration, f_λ is obtained from the equation of Kuchta et al.,[6]

$$f_\lambda = \left(\frac{R/v}{\lambda + R/v}\right)\left(\frac{\lambda}{\lambda + R/V}\right) \quad . \tag{5}$$

Deemanations of a ^{232}Th solution into the collection apparatus were carried out at a flow rate of 1.2 L min^{-1} to determine the optimal voltage on the collection electrode. The maximum output of the voltage supply was 5.8 kV. The results, shown in Table 1, suggest that the collection efficiency vs. voltage approaches a plateau at 5.8 kV.

Table 1. Collection efficiency vs. voltage (flow rate = 1.2 L min^{-1}).

Voltage, kV	Relative efficiency (±S.E.)[a]
0	0.00020 ± 0.00001
2.0	0.86 ± 0.01
3.0	0.88 ± 0.01
4.0	0.95 ± 0.01
5.8	1

[a]Errors reflect the errors in the analysis of the counting results only.

An experiment was carried out to determine whether decay products produced in the mask and the mask-to-chamber tubing contribute to the collection efficiency. A deemanation of the ^{232}Th solution into the apparatus at 1.2 L min^{-1} was carried out with a filter placed at the inlet of the collection chamber. The ^{212}Pb activity on the filter was < 2% of that to be expected if all decay products of thoron produced in the air volume of the deemanation bottle and the tubing leading to the chamber during the period of deemanation were trapped by the filter. Most of the expected decay-product activity was found by gamma-ray measurement to be deposited on the surface of the 2.5 cm diameter polyethylene tube (0.36 L air volume) that carried the thoron-bearing air to the inlet of the collection chamber. The remainder presumably was deposited on the surfaces of the deemanation bottle and solution and on the surface of the 0.6 cm diameter tube leading from the deemanation bottle to the larger-diameter tube. These results indicate that, should any decay products of thoron arriving at the inlet to the collection chamber retain a positive charge, their contribution to the efficiency of the apparatus would be negligible.

Method of Calibration

The calibration was carried out by deemanating thoron into the collection apparatus at a flow rate of 1.2 L min^{-1} from a solution containing 20.4 mg (82.5 Bq) ^{232}Th, while simultaneously sampling a normal subject's expired air. The ^{232}Th solution was prepared with old thorium nitrate so that ^{232}Th and its decay products, ^{228}Ra, ^{228}Th, and ^{224}Ra, were virtually in secular radioactive equilibrium.

The thoron-bearing deemanating air was mixed with the normal subject's expired air at a point between the collector head and the inlet of the collection chamber (Figure 1). The average volume of air flowing per minute through the collection apparatus beyond this point was the sum of the subject's respiratory minute-volume (volume of air exhaled per min) and the 1.2 L minute-volume of the deemanating air, which was measured by a flow-rate meter at the outlet of the deemanation bottle. The average flow rate R was determined from the total volume of air that flowed through the apparatus during the period of simultaneous breath-sampling and deemanation. This total volume was measured by a wet-test meter connected to the outlet of the collection chamber (Figure 1).

The air volume of the deemanation bottle and the tubing from the bottle to the point of entry of the deemanated thoron into the mouth-to-chamber lead was 0.34 L. The fraction of deemanated thoron atoms that survived decay to this point was 0.81 if the air flow was smooth (Eq. 2, v = 0.34 L, R = 1.2 L/min), or 0.82 if the air flow was mixed (first term of Eq. 5). The fractional deemanation efficiency at a flow rate of 1.2 L/min was estimated by Kuchta et al.[6] to be 0.815. Therefore, the effective activity of freely emanating ^{224}Ra was (0.81) (0.815) (82.5 Bq) or 54.5 Bq. The value of the overall efficiency E was obtained by dividing 54.5 Bq into the equilibrium ^{212}Pb counting rate determined from the least-squares fit to the alpha-particle counting results.

Deemanation of the ^{232}Th solution by having the normal subjects exhale into the deemanation bottle was not attempted because to have done so would have required modification of the bottle to accommodate splashing of the solution at the higher flow rates, and rather lengthy experiments would have been required to determine deemanation efficiencies.

Fifteen-minute deemanations with each of seven different normal subjects exhaling into the apparatus and four deemanations unaccompanied by normal-subject exhalation were carried out to determine the overall efficiency of the apparatus over a range of flow rates. A separate determination of the counting efficiency was made.

Results

Values of the overall efficiency E observed at eight different flow rates R are set out in Table 2, together with values of f_λ for smooth flow obtained from Eq. 4 (v = 0.36 L, V = 36 L), and corresponding values of $f_c\eta$ (the product of the collection and counting efficiencies). The values of E (observed) were adjusted to allow for the fraction of exhaled thoron atoms that would have decayed in the 0.22 L free volume of that portion of the mouth-to-chamber tubing above the point of entry of thoron into the collection apparatus.

The value of f_λ at 1.2 L min^{-1} for mixed flow obtained from Eq. 5 (v = 0.36 L, V = 36 L) is 0.78, close to the value of 0.80 for smooth flow (Table 2). If mixed flow at the higher flow rates had been assumed, values of f_λ would have been about 20% lower than those listed in Table 2 and corresponding values of $f_c\eta$ would have been 25% higher. The close agreement between the

Table 2. Overall efficiency E, expected value of f_λ, and derived value of $f_C\eta$ at eight experimental values of average flow rate, R.[a]

R, L/min	E (observed)[b]	$f\lambda$ (expected)[c]	$f_C\eta$ (col. 2 ÷ col. 3)	E (adjusted)[d]
1.2	0.47 0.52 0.30 0.46	0.80	0.55 ± 0.070	0.38 ± 0.042
7.5	0.54	0.94	0.57	0.53
7.7	0.53	0.94	0.56	0.52
7.9	0.56	0.93	0.60	0.55
8.1	0.47	0.93	0.51	0.46
9.2	0.46	0.92	0.50	0.45
9.6	0.52	0.91	0.57	0.51
11.6	0.48	0.88	0.55	0.47
Mean (n = 7)			0.55	0.50
Standard error			± 0.013	± 0.015
Standard deviation			± 0.035	± 0.039

[a] E, f_λ, and $f_C\eta$ are dimensionless.

[b] The relative standard error derived from the analysis of the counting results is < 1% for all values of E in this column.

[c] From Eq. 4 (v = 0.36 L, V = 36 L).

[d] E (adjusted) = col(2) x f_S (Eq. 2; v = 0.22 L).

average values of $f_C\eta$ at 1.2 L min^{-1} and at the higher flow rates (Table 2) apparently validates the assumption of smooth flow in calculating values of f_λ.

The variation of the overall efficiency E with flow rate R is adequately described by Eq. 1, where f_λ is given by Eq. 4 (v = 0.58 L, V = 36 L) and $f_C\eta$ has the value 0.55 ± 0.035, i.e.,

$$E = (0.55 \pm 0.035)(e^{-0.441/R} - e^{-27.8/R}) \quad . \tag{6}$$

The fit of Eq. 6 to the adjusted values of E in Table 2 is shown in Figure 2. The optimal respiratory minute-volume, at which E is at a maximum of 0.506 ± 0.032, is 6.6 L.

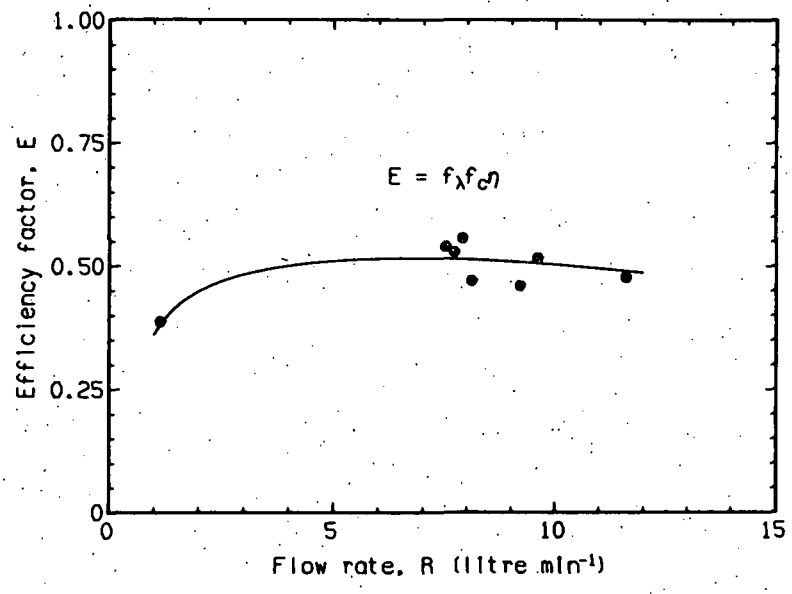

FIG. 2.--Overall efficiency E vs. flow rate R. The points are the adjusted experimental values of overall efficiency (Table 2) and the curve is described by Eq. 6.

Counting Efficiency

In the apparatus described by Aub et al.,[1] the fractional counting efficiency was about 0.25 because only one side of the electrode disk was counted and half the alpha particles were directed into the disk. Later, as reported by one of us,[8] nearly 4-π counting geometry was attained by the use of phosphors and photomultipliers. The counting arrangement currently in use has been described in detail by Kuchta et al.[6]

The efficiency of the alpha-particle counters was determined by deemanating a 2.0 kBq ^{232}Th solution and collecting thoron decay products. After the collection, the phosphor-coated electrode was placed in a Lucite holder containing a second phosphor and counted for a 10 min period in each of

eight alpha-particle counters. The variability in efficiency between counters was no greater than that expected from counting statistics (relative standard deviation ± 0.4%). The source was then counted repeatedly for several hours in one counter and the ^{212}Pb activity on the phosphor at the end of collection was determined by a weighted least-squares fit to the data, with 100% counting efficiency assumed.

The phosphor disks were removed both from the copper electrode and from the Lucite holder at the completion of the alpha-particle counting, and the rate of emission of the 2.61-MeV gamma rays of ^{208}Tl from the phosphor sandwich was determined by comparison with a point-source NBS ^{228}Th standard. The observed gamma-ray emission rate was compared with that expected from the results of the alpha-particle counting to obtain an estimate of the alpha-particle counting efficiency. This experiment was carried out twice, giving values of 0.95 ± 0.023 and 1.0 ± 0.025 for the fractional efficiency (count per alpha). The standard errors in the two determinations did not include a relative systematic standard error of ±2.4% in the correction for decay of ^{228}Th (1.91 ± 0.009 yr half-life) in the NBS source since its standardization about 13 years earlier. This systematic error was subsequently propagated with the standard error of ± 0.025 in the weighted mean of the two results. The fractional efficiency η of the alpha-particle counters was, therefore, estimated to be 0.973 ± 0.034.

Collection Efficiency

The mean value of $f_c\eta$, the product of the fractional collection and counting efficiencies obtained from the data in Table 2, is 0.55 ± 0.013, from which we deduce a value for f_c of 0.57 ± 0.041 over the range of experimental flow rates.

The collection efficiency refers only to the thoron daughter-product activity collected on the electrode phosphor. In a deemanation experiment carried out with a smaller collection chamber (3.8 L), it was found that the thoron-daughter activity deposited on the phosphor disk was 87% of the total activity deposited on the electrode. Of the activity not on the phosphor, 90% was deposited on the edge of the copper disk, and the remainder was deposited on the back face.

Since the variability in the values of E at the higher flow rates (Table 2) is considerably less than the variability at 1.2 L min^{-1}, the lowest value

of E among the four observed at 1.2 L min^{-1} may have been atypical. This suggests that the high voltage applied to the collection electrode should be monitored in case a voltage drop should occur during sampling. When the lowest value of E at 1.2 L min^{-1} is excluded, the value of $f_C\eta$ implied by the three remaining values of E is 0.60 ± 0.019. The apparently lower values of $f_C\eta$ at the higher flow rates might then indicate that there was a partial mixing of flow air at the higher rates or that the effective strength of the electric field for decay products of thoron was lower at the higher rates.

Variability

The median coefficient of variation of thoron activity outside the body in replicate measurements of the expired air of former thorium workers is ± 0.15. This coefficient is presumed to be a measure of random temporal variability in the fractional exhalation of thoron. The relative standard deviation (± 0.064) of the distribution of the values of $f_C\eta$ (Table 2) is interpreted as the relative systematic standard error in the value of the overall efficiency E (Eq. 6), even though this variability may be due in part to random fluctuations in deemanated thoron or in the efficiency factors at a given respiratory minute-volume. The overall standard error in a single determination of freely-emanating ^{224}Ra (FX) is

$$[(0.15)^2 + (0.064)^2 + C^2]^{1/2}\ FX \quad ,$$

where FX is equivalent to the thoron activity outside the body and C is the relative standard error of the alpha-particle counting results.

Comments

In an earlier provisional determination of overall efficiency of the apparatus, results obtained from the deemanations of 0.41 and 82.5 Bq ^{232}Th solutions at 1.2 L min^{-1}, using nitrogen as the flow gas, were extrapolated to a respiratory minute-volume of 8 L. The mean value of E at 1.2 L min^{-1} was 30% lower than the mean value obtained at that flow rate in the present experiment. No reason for the lower value has been ascertained. In the provisional estimate of E, the value of f_λ at 8 L min^{-1} was the average obtained from Eq. 4 (smooth flow) and Eq. 5 (mixed flow). The value of E

calculated for 8 L min^{-1} was 0.32 ± 10%, which is 36% lower than the value found in the present experiment. An excursion from normal variability of similar magnitude was observed at 1.2 L min^{-1} in the present experiment (Table 2). The relative frequency of its occurrence merits investigation of its cause.

The optimal respiratory minute-volume of 6.6 L for the apparatus is lower than the experimental minute-volumes in Table 2. The collection-chamber volume V and the volume v of the mask and the mask-to-chamber tubing can be made optimal for any desired minute-volume. The expression for the optimal minute-volume R_{opt}, which is obtained by setting to zero the derivative of the efficiency factor f_λ (Eq. 4) with respect to R^{-1} and solving for R, is

$$R_{opt} = \frac{\lambda V}{\ln(\frac{V}{v} + 1)} \quad . \tag{7}$$

R_{opt} varies directly with V and v. The efficiency factor f_λ varies directly with V and inversely with v. Therefore, an increase in the capacity V of the collection chamber with no change in v will yield both a higher optimal minute-volume and a higher efficiency. A decrease in v with no change in V will yield a lower optimal minute-volume and a higher efficiency. However, the gain in efficiency is limited by the thoron decay-constant λ. For example, an increase in the chamber volume from 36 to 62 L, with v held at 0.58 L, makes the apparatus optimal for a minute-volume of 10 L, but the maximal value of 0.947 for f_λ obtained from the 72% increase in V is only 6% higher than the value of f_λ at a minute-volume of 10 L obtained with a 36-L chamber.

For a 50 min period of breath sampling and a counting period of two or three ^{212}Pb half-lives, the limit of detection of thoron activity outside the body, defined as a result lying two standard errors above zero activity, is about 10 mBq (0.27 pCi). This corresponds to a thoron exhalation rate of 130 μBq (3.5 fCi) sec^{-1}. The counting rate of a blank phosphor-coated electrode in the Lucite holder averages about 10^{-4} sec^{-1}.

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DETERMINATION OF THE ^{226}Ra CONCENTRATION IN A NEW BRUNSWICK LABORATORY STANDARD PITCHBLENDE SAMPLE

R. B. Holtzman and F. Markun

The ^{226}Ra concentration determined by the radon emanation method in a sample of NBL Reference Material No. 6-A, pitchblende ore was 192.6 ± 1.3 ng $^{226}Ra/g$ ore. The weight ratio of radium to natural uranium was (3.344 ± 0.06) x 10^{-7}. This value is not significantly different from the value of 3.374 x 10^{-7} expected if the radium were in radioactive equilibrium with its ^{238}U parent.

To enhance the usefulness of standard reference materials the New Brunswick Laboratory is having values determined for the content of ^{226}Ra to allow their use as accurate standards for ^{226}Ra, as well as for uranium (U_3O_8). Reported here are the results of the determination by the radon emanation method of the ^{226}Ra concentration in NBL Reference Material No. 6-A, pitchblende ore,* which contains 67.91 ± 0.05% U_3O_8.[1]

Methods

In this analysis three weighed samples of the material were dissolved and the radium content was determined by the radium deemanation method of Lucas.[2,3]

The general procedure was as follows:

1. Three samples of about 100 mg each were taken from the bottle, carefully weighed, and placed in 50 ml Teflon beakers.

2. The samples were dissolved by heating in nitric acid, and dissolution was completed by the subsequent addition of a small amount of hydrofluoric acid.

3. After the solids were dissolved the solutions were partially evaporated, and the HF was removed by repeated volume reductions and additions of hydrochloric acid.

4. Each solution was diluted to 100 ml in a volumetric flask, and a 10.0 ml aliquot of each sample was then added to its respective 600 ml deemanation flask. This was diluted with water to about 300 ml. The

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aliquoting was done with calibrated volumetric glassware, but it was also checked by weight.

5. The flask was then flushed with radon-free air to remove residual radon, and the radon ($T_{1/2}$ = 3.825 days) was allowed to grow in for two or three days.

6. The radon was flushed from the flask with radon-free air and collected on a charcoal trap cooled in dry ice.

7. The radon on the trap was transferred to a radon counting bottle, which was then placed on a counter, and the radium content of the aliquot was determined by the standard procedure.[2,3]

The determination was made twice on each sample.

Results

The results of the individual analyses are shown in Table 1. The standard deviations shown are based on counting statistics, propagated with a 1% uncertainty due to variations in the characteristics of the radon counting bottles. The uncertainties of the radium standard used to calibrate the system are not included here.

Table 1. ^{226}Ra concentrations in the individual samples.

Sample no.	Sample size, mg		^{226}Ra content	
	Total	Aliquot	ng/sample ± S.D.	ng/g ore ± S.D.
1	100.2	10.07	1.932 ± 0.020	191.9 ± 2.0
			1.970 ± 0.021	195.6 ± 2.1
2	99.7	10.03	1.891 ± 0.020	188.5 ± 2.0
			1.898 ± 0.021	189.2 ± 2.1
3	101.2	10.20	1.979 ± 0.021	194.0 ± 2.1
			2.001 ± 0.022	196.2 ± 2.2
			Mean ± S.E.	192.6 ± 1.3

The mean of the six determinations was 192.6 ± 1.3 (SE) nCi/g ore. The values for sample 2 appeared to be lower than those of the others, but an analysis of variance showed that the level of significance, P = 0.074, was somewhat greater than that considered to be "probably" significant (P = 0.05),

i.e., the values for this sample were not significantly lower than those for the others.

From the Appendix, the elemental uranium content is 0.5759 g/g ore, and from Table 1, the ^{226}Ra concentration is 192.6 ng/g ore, so that the ratio of weights is

$$\frac{W_{Ra}}{W_U} = \frac{192.6 \times 10^{-9}}{0.5759} = 3.344 \times 10^{-7} \quad .$$

This ratio is somewhat lower than the equilibrium value expected, 3.374×10^{-7} (Appendix), and about 3% lower than the 3.44×10^{-7} listed on the Certificate.[1] The uncertainty in the ratio, based on the values given on the Certificate for the uranium content and the results of our analysis of the radium content, is about ± 0.68%, but the systematic errors in the analysis are substantially greater than this. The analysis system is calibrated against two National Bureau of Standards Radium-226 Standards for Radon Analysis, Nos. 4950-B and 4951 (8.069×10^{-10} and 10.01×10^{-11} g ^{226}Ra, respectively). The former was assigned an uncertainty of ± 1.0% at the 95% confidence level (in 1968), and the latter had total uncertainties (less clearly stated) of about ± 0.3% (in 1956). The overall errors in calibration are about 2%.

Thus, it appears that the ratio of $^{226}Ra/U$ obtained from our analysis of 3.344×10^{-7} has an uncertainty in precision of about ± 0.023×10^{-7} and about ± 0.06×10^{-7} for a total uncertainty. This is well within the range of the theoretical value of 3.374×10^{-7} for radioactive equilibrium (see Appendix) and the value of 3.44×10^{-7} listed on the Certificate of Analysis.[1] The data and results are summarized in Table 2. If we assume that the radium is actually in radioactive equilibrium with the uranium, the closeness of the theoretical and measured values indicates that the estimate of the standard error in the calibration is actually less than the 2% stated above, and might be only about 1% overall. Further efforts are being made to improve the calibration of the system.

Table 2. Summary of results.

A. Concentrations

Nuclide or element	Concentration in ore
^{226}Ra	192.6 ± 1.3 ng/g
Uranium as U_3O_8 (certificate)[a]	67.91 ± 0.05%
Uranium, elemental (calculated)[b]	57.59 ± 0.04%

B. Ratio of weights

Source	Ratio $^{226}Ra/U$, x 10^7
Certificate of analysis	3.44
Theoretical, radioactive equilibrium[b]	3.374
This work	3.344 ± 0.06

[a]Ref. 1.
[b]Appendix, this paper.

APPENDIX. Calculation of ratio of ^{226}Ra to uranium.

The atomic and weight ratios of ^{226}Ra to uranium may be calculated from the parameters set out in Table A1.

Table A1. Properties of the elements and radionuclides of interest.[a]

Element or nuclide	Atomic weight[a]	Half-life, yr[b]	Isotopic abundance in element, %[a]
Oxygen	15.9994	-	100.00
Uranium(natural)	238.029	-	100.00
^{238}U	238.05079	(4.4683 ± 0.0023) x 10^9	99.2746
^{226}Ra	226.0254	1599 ± 7	-

[a] Ref. 4.
[b] Ref. 5.

The concentration of U_3O_8 in the ore is given as 67.91 ± 0.05% on the Certificate of Analysis.[1] The concentrations of uranium and of the nuclide of interest, ^{238}U, are then 0.5759 g/g ore and 0.5718 g/g, respectively. If the ^{226}Ra is in radioactive equilibrium with the ^{238}U, their activities are equal, and the expected concentration of ^{226}Ra can be readily deduced as 3.579×10^{-7} atom of ^{226}Ra per atom of ^{238}U. Multiplication of this ratio by the value of the atom percent abundance of ^{238}U gives the atomic ratio of ^{226}Ra to natural uranium of 3.553×10^{-7}. This, in turn, multiplied by the ratio of atomic weights gives the weight ratio of $^{226}Ra/U$ (nat.) of $(3.374 \pm 0.017) \times 10^{-7}$. The uncertainty (± 0.5%) in the latter value is determined primarily by the uncertainty (± 0.44%) in the half life of ^{226}Ra.

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^{226}Ra CONCENTRATIONS IN SOME ILLINOIS WELL WATERS

R. B. Holtzman and R. H. Gilkeson*

^{226}Ra concentrations are reported for the waters from deep wells in 43 communities in Illinois. The concentrations range from 0.08 to 20.6 pCi/L. The effectiveness of additives (nitric acid or EDTA) in keeping the ^{226}Ra in solution in the samples is discussed.

Introduction

The advent of stricter standards for the quality of potable waters instituted by the U. S. Environmental Protection Agency[1] has greatly increased interest in studies of trace element and radionuclide concentrations in these waters. The concentrations of ^{226}Ra, and to a lesser extent, those of ^{228}Ra have been shown to be high in waters from many of the wells in Illinois and adjacent states.[2-4] These waters were mainly from the Ironton-Galesville Sandstones which are 300 m or more deep. The ^{226}Ra concentrations range up to about 30 pCi/L. To determine the mechanisms controlling the concentrations of ^{226}Ra and various elements, such as barium, in the waters, one of us (RHG) has been collecting numerous samples throughout the region of interest. Various chemical and physical properties have then been determined on these samples. Presented here are the results of determinations of ^{226}Ra in water samples from 43 communities.

Methods

Samples of water of one to four liters were collected and, in most cases, a stabilizing preservative (either 5 ml/L of nitric acid or 5 g/L of disodium ethylenediaminetetraacetate [EDTA]) was added to maintain the radium in solution. In addition, the water may have been filtered through a 0.45μm membrane filter.

The ^{226}Ra was determined by the radon deemanation method of Lucas[5,6] in which about 300 ml of the water to be analyzed was placed in a 600 ml

*Illinois State Geological Survey. Funds provided in part by a grant from the U. S. Department of the Interior, and administered by Professor Glen Stout, Director of Water Resources Center, University of Illinois, Champaign, Illinois.

deemanation flask. Radon-free air was bubbled through the water to remove residual radon from the flask, after which the flask was sealed, and radon was allowed to grow for a known time greater than three days.

At the end of the period radon-free air was again passed through the flask and through a dry-ice cooled charcoal trap, which preferentially adsorbs radon from the air. The radon was transferred from the trap to a radon counting chamber, which was then placed on a photomultiplier detector; the amount of radon was determined from the alpha counting rate.

About halfway through the study, the 600 ml flask was replaced by a low-cost disposable bottle with a septum as described in the Appendix.

Results and Discussion

The results of the measurements are listed in Table 1 by community in alphabetical order. In addition to samples collected for the aforementioned studies, one group was collected by the Metropolitan Sanitary District of Greater Chicago and another by the Illinois Environmental Protection Agency, as noted in the table. Also shown are the treatments of the samples, viz., the addition of EDTA or nitric acid, and/or filtration of the water.

The relative effects of preservative treatment cannot be deduced from these data, but other data indicate either no significant differences, or a slight superiority for the use of nitric acid, i.e., the activities appear to be slightly higher with nitric acid, which is an indication of less adsorption of the radium. The use of this acid is also advantageous in that a sample evaporated for the determination of gross alpha-particle activity has no additional residual solids derived from the preservative to increase the self-absorption of alpha particles. On the other hand, EDTA at a concentration of 5 g/L may provide most of the residue found in the sample on evaporation.

Filtration appears to have an effect in many cases, but the differences between filtered and unfiltered samples are not consistent. The effects could be due to statistical variations in the determination; to the removal of adsorbed activity on the filter, which would reduce activity in the filtrate; or to the adsorption of radium onto the particles in the unfiltered sample during storage, i.e. reduced emanating activity. In most cases the differences were not statistically significant.

These data show levels of ^{226}Ra in the waters studied that are higher than those allowed by the EPA standards. These values are not necessarily

Table 1. Concentrations of ^{226}Ra in well waters in Illinois.

Community	Well number	Date of collection, M/D/Y	Treatment[a]	Concentration,[b] pCi ^{226}Ra/L
Amboy	5	10/20/80	E	2.60
Arlington Heights	6[c]	8/19/76	-	6.24
	7	7/30/80	F	8.81
	16	7/30/80	-	4.12
Ashton	1	10/14/80	F,N	0.08 ± 0.02
Aurora	20	4/23/80	E,F	10.6
Bartlett	4	10/3/80	E,F	6.31
Batavia	4	12/6/79	E	4.79
Bellwood				
Buffalo Grove	3[c]	8/20/76	E	6.34
	6	12/20/79	E,F	4.44
Bensenville	-	10/3/79	E	8.17
Burlington	-	9/27/79	E,F	4.17
	-	9/27/79	E	5.19
Carthage	1	11/4/80	N	16.6
Coal City	4	8/21/80	E	9.23
	3	8/21/80	E,F	8.92
	5	8/21/80	E	15.4
	5	8/21/80	E,F	18.6
Crystal Lake	-	12/29/79	N,F	3.01
DeKalb	11	10/14/80	N	2.84
DePue	2	10/15/80	E	9.93
Elgin	1	9/21/79		5.04
	1	9/21/79	F	5.04
	1A	8/1/80	E	7.03
	2[d]	3/7/75	E	4.79
	2	8/1/80	E	4.76
	3[d]	3/7/75	E	4.91
	3[d]	8/1/80	E	4.38
	3A	7/31/80	E	5.03
	3A	10/28/80	E,F	3.82

Table 1 (cont.)

Community	Well number	Date of collection, M/D/Y	Treatment[a]	Concentration[b] pCi ^{226}Ra/L
Elgin (cont.)	4A	11/29/79	E,F	4.43
	4A	11/29/79	E	4.63
	5	12/6/79	E,F	4.70
	5	12/6/79	E	4.87
	5A	11/29/79	E,F	8.81
	5A	11/21/79	E	8.40
	5A	8/1/81	E	8.08
	5A	12/6/79	E,F	7.55
	5A	12/6/79	E	8.07
	6[d]	3/7/75	E	13.0
	6	12/5/79	E	13.4
	6	12/5/79	E,F	13.6
	6	12/12/79	N	12.4
	6	12/12/79	N,F	13.0
	6	12/10/79	-	10.3
	6	12/10/79	E	13.2
	6	12/10/79	F	12.6
	6	12/10/79	E,F	13.2
	Airlite Wells Composite	8/1/80	F	5.91
Elk Grove	4[c]	8/20/76	-	3.99
Elmhurst	4	10/29/80	N	5.51
	Tap	11/27/74	-	4.90
Geneva	-	12/5/79	E	6.45
			E,F	6.20
Gurnee	1	12/20/79	N,F	8.97
Hanover Park	4[c]	8/23/76	E	8.86
	3	10/29/80	E	4.91
	4	10/29/80	E	13.4
Hersher	5[c]	3/25/75	E	14.9
		3/25/75	E	14.3
				14.9
	5[c]	4/1/75		14.2
				14.4
	5[c]	4/1/75	E	14.0
		4/8/75	E	13.9
		4/8/75		14.3

Table 1 (cont.)

Community	Well number	Date of collection, M/D/Y	Treatment[a]	Concentration,[b] pCi ^{226}Ra/L
Hersher (cont.)		4/8/75		14.1
		4/8/75		14.0
Hoffman Estates	12	10/29/80	E	3.83
		10/29/80	N,F	4.82
		10/29/80	F	4.47
Homewood	12	10/30/80	N	3.40
			N,F	2.32
Kingston Mine		11/79	E	10.5
Lemont	1[c]	8/31/76	-	14.7
Lockport	4	11/18/80	N	10.7
Lynwood	-[d]	3/27-4/10/75	E	
(10 samples)		Mean ± S.D.		14.69 ± 0.24
	-	8/4/79	E,F	
(4 samples)		Mean ± S.D.		15.18 ± 0.67
Macomb	2	11/6/80	N	18.7
			N,F	20.6
Marseilles	4	8/22/80	E,F	3.39
Mendota	-	9/26/79	E	3.22
			E,F	3.15
Morris	4	8/21/80	E	8.33
Mount Prospect	?	12/21/79	E	5.54
	?	12/21/79	E,F	5.58
Naperville	16	10/17/70	E	3.66
		10/17/70	E	3.15
Odell	1	8/21/80	E	9.56
	1	8/21/80	E,F	10.7
Orland Park	6	12/17/80	N	7.84
	9	12/17/80		15.4
	10	12/17/80		4.44
	11	12/17/80		16.6

Table 1 (cont.)

Community	Well number	Date of collection, M/D/Y	Treatment[a]	Concentration[b], pCi ^{226}Ra/L
Peru	5[d]	3/4/75	E	4.78
		2/25/75	E	4.57
	6[d]	3/4/75		3.11
	7[d]	2/25/75		6.07
		3/4/75		6.07
	8	12/4/79	-	6.51
			F	5.94
Princeville	3	11/79	E	14.04
Shannon	-	9/26/79	E	6.51
Stronghurst	1	11/11/80	N	17.4
Table Grove	1	11/4/80	N	15.1
West Chicago	4	10/3/79	E	15.2
		10/3/79	E,F	12.6
	5	10/3/79	E	9.39
		10/3/79	E,F	9.50
Yorkville	4	12/21/79	E	7.22
			E,F	7.23
			N	7.60

[a]F - filtered
E - EDTA added, 5 g/L
N - nitric acid added 10 ml/L

[b]Coefficient of variance ± 3%, except as noted.

[c]Collected by the Metropolitan Sanitary District of Greater Chicago.

[d]Collected by the Illinois Environmental Protection Agency (Ref. 3).

typical of those in Illinois; the wells sampled were chosen because the radium concentrations were expected to be high given the characteristics of the source or based on previous information. Further, it should be noted that the measurements were made on raw water which does not necessarily represent that distributed to the consumer; the water may have been softened or mixed with waters low in radium (from surface sources or shallow wells) which would substantially reduce the radium concentrations over that of the water from the deep wells listed here.

The samples collected in 1975 and 1976 provide some evidence on the variability of the ^{226}Ra concentrations in cases where more recent samples from the same wells were also collected, e.g., Elgin wells #2 and #6 and Lynwood. The waters from Lynwood, especially, show no statistically significant change between 1975 and 1979.

Work is in progress to determine the levels of ^{228} Ra in the waters and the relationships between gross alpha activity and radium content.

APPENDIX. Low-Cost, Easy Maintenance Deemanation Flask

R. B. Holtzman, F. Markun and E. Y. Hwang

Because of the difficulties in maintaining, using and cleaning the standard deemanation flask (especially its greased stopcocks) used in the radon deemanation procedure for the analysis of radium in water,[5,6] we developed the use of a simpler container. Such a container should hold 200 to 300 ml of sample with an equal volume of head space; it should be easy to clean or be disposable. It should retain the radon over a period of several weeks, and the deemanation procedure should be simple and quantitative. Lucas had proposed the use of a narrow-mouth bottle,[7] and later he used a serum bottle with a septum,[8] which is no longer available.

We have developed a suitable sample container consisting of a 16 ounce (480 ml) prescription bottle with a plastic cap and butyl rubber septum, shown in Figure 1. The radon is deemanated by inserting through the septum a 16 gauge, 9 inch (23 cm) long hypodermic needle through which air is passed and bubbled through the solution in the bottle. The air carrying the radon is extracted through a shorter (~2.5 inch, 6.5 cm) hypodermic needle in the septum. Each needle is connected to a 1 cm^3 syringe the body of which has been cut off about 2 inches above the tip for connection to rubber tubing.

Because the cap with the septum did not seat properly on the bottle, we used the cap that came with the bottle by drilling a hole in it to accommodate the septum, which was glued into the cap with Pliobond Industrial Adhesive* to keep it in position when the hypodermic needles were forced through it. Other rubber adhesives would probably be suitable.

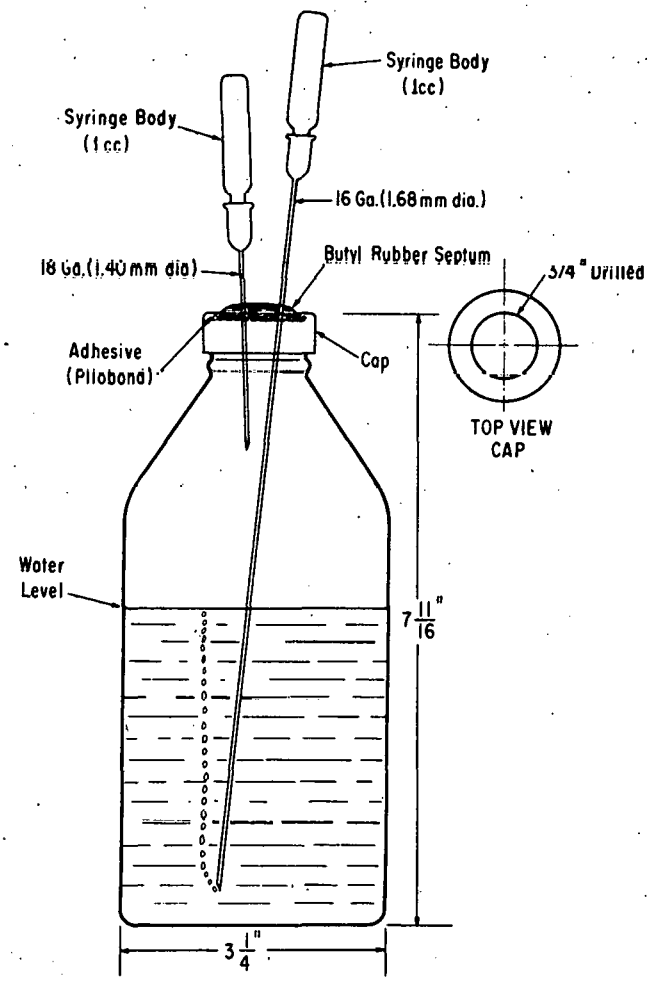

FIG. 1.--Diagram of deemanation flask: 16 oz. Prescription Bottle, Wheaton Scientific, 1000 North Tenth Street, Millville, NJ 08332, Cat. No. 222889 and Plastic Cap with Butyl Septum, Cat. No. 240680, Size 33-430.

This system worked well. Despite the tendency of radon to diffuse through rubber and plastics, loss of radon through the butyl rubber septum was negligible; the concentrations of radium in aliquots of water samples analyzed

*Goodyear Tire and Rubber Company, Akron, Ohio 44316

in the standard 600 ml flasks were essentially identical to those of aliquot portions analyzed in the septum bottles. While this bottle was tested only on the water samples, it should work equally well with solutions such as those of bone and soft tissues, with the limitation that chlorides, such as hydrochloric acid, not be used because they may attack the stainless hypodermic needles.

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^{226}Ra AND ^{228}Ra IN GROUND WATER OF THE CAMBRIAN-ORDOVICIAN AQUIFER SYSTEM IN NORTHERN ILLINOIS*

Robert H. Gilkeson† and Richard B. Holtzman

Over a large region of Illinois, ground water of the Cambrian-Ordovician Aquifer System exceeds the U.S. EPA drinking water standard of 5 pCi/L for the combined concentration of ^{226}Ra and ^{228}Ra. ^{226}Ra concentrations range from <1 pCi/L in dilute ground water in north-central Illinois (where the aquifer is unconfined) to 25 pCi/L in highly mineralized ground water in central Illinois (where the aquifer is confined by shale bedrock). An important control on the activity of ^{226}Ra is the geochemistry of uranium in the ground-water flow system, while the ^{228}Ra activity in ground water which ranges from <1 to 13 pCi/L depends mainly on the primary deposition of ^{232}Th-bearing minerals in the aquifer strata.

The comparison of recent analyses to historical data gathered over the last 20 years indicates that, with few exceptions, ^{226}Ra and ^{228}Ra activities in ground water have remained constant. The ratio of ^{228}Ra to ^{226}Ra did not vary at specific well sites but ranged from 0.04 to 2.43 throughout the study area. The combined concentrations of the two nuclides in ground water of the aquifer system ranged from <1 to 29 pCi/L. Over large regions where the ^{226}Ra concentrations were high (≥10 pCi/L), those of ^{228}Ra were low (≤2 pCi/L), but, with few exceptions, in regions where ^{228}Ra concentrations were high (≥5 pCi/L), those of ^{226}Ra were also high (≥5 pCi/L). Low concentrations of ^{226}Ra (≤3 pCi/L) were usually accompanied by low concentrations of ^{228}Ra (≤2 pCi/L). The large range in the $^{228}Ra/^{226}Ra$ ratio indicates that ^{228}Ra activities cannot be predicted accurately from analysis of ^{226}Ra. The range of values raises questions concerning the validity of the U.S. EPA regulation which requires analysis for ^{228}Ra only when the concentration of ^{226}Ra exceeds 3.0 pCi/L.

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RARE EARTH AEROSOL ANALYSIS BY X-RAY FLUORESCENCE SPECTROMETRY

Irvin M. Citron* and Leonard F. Mausner†

An analytical method for the determination of four lanthanides in air filter samples is described. The method involves simultaneous quantitative determinations of La, Ce, Pr, and Nd at the microgram level by x-ray fluorescence spectrometry without chemical separation of these rare earths and without serious interferences from the dust matrices on the filters. The method has been used successfully to analyze some air filter samples collected at a rare earth processing refinery in Illinois. A description of the development of the method is given as well as the results obtained by using this method on the air filter samples. The reproducibility of the results was generally ± 5%.

Introduction

The identification, characterization and measurement of pollutants in the ambient atmosphere are essential to the solution of a wide variety of environmental problems. X-ray fluorescence analysis has emerged as a powerful technique for the evaluation of the abundance of trace elements in airborne particulate matter. Several features make it especially advantageous for aerosol analysis. These attributes include (1) the nondestructive nature of the measurement, (2) the ability to analyze filter deposits directly with little or no sample preparation, (3) multielement determinations with fairly uniform detectability for all elements from fluorine upward, and (4) the availability of commercial instruments which permit a large number of sample irradiations in relatively short intervals.

Quantitative analysis of the individual rare earths, particularly at trace levels, has been a traditionally difficult analytical problem. Although optical emission spectroscopy, mass spectrometric isotope dilution and neutron activation all have been used, interelemental interferences or varying elemental sensitivities often mandate the difficult chemical separation of the rare earths from each other. In contrast, energy dispersive x-ray

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fluorescence spectrometry (XRF) is capable of simultaneous measurement of the rare earths with essentially equal sensitivity.

Specifically, our need to make such measurements arose as part of our study of the health effects of occupational exposure to thorium and rare earths at a thorium and rare earth processing refinery in Illinois. Since the major type of exposure was considered to be through inhalation, it is obviously of interest to characterize the airborne concentrations of thorium and the rare earths. We have obtained over 10,000 air filter samples, which were collected by plant personnel during operations from 1962 to 1973. Thorium was determined by radioactivity measurements. Fortunately the filter medium used, Whatman 41 paper filters, is very appropriate for direct analysis of the lanthanides by XRF. This paper has a moderate areal density (8 mg/cm^2) and a very low trace element content. We describe here our general procedures as a demonstration of the utility of energy dispersive x-ray fluorescence spectrometry for rare earth aerosol analysis.

Method

The basis of the x-ray fluorescence technique is shown schematically in Figure 1. The incident radiation (x rays shown here) ionizes an inner atomic

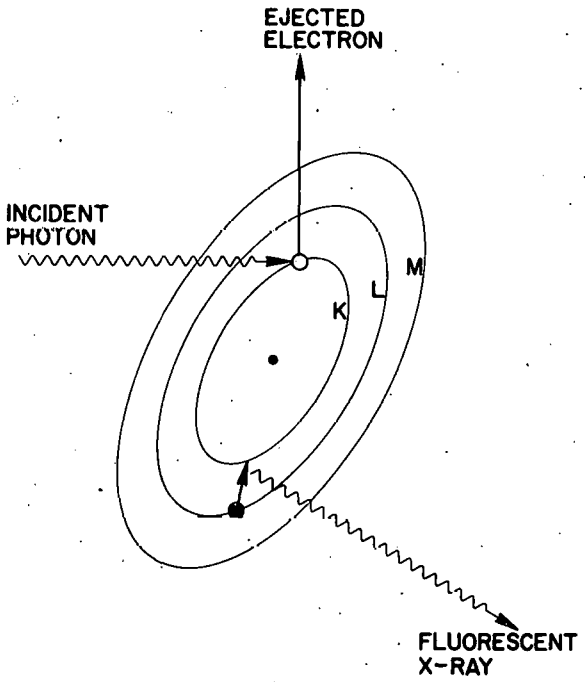

FIG. 1.--Schematic diagram of the creation of fluorescent x rays.

electron creating an inner shell vacancy. An electron from a higher shell de-excites to fill this vacancy and the de-excitation energy is carried off by a fluorescent x ray. The energy of this x ray is characteristic of the emitting atom. X rays from the sample are detected and their energies measured by a semiconductor detector. The radiation creates in the detector a voltage pulse with an amplitude proportional to the energy of the incident x ray.

The instrument used in this work was a secondary source system. In such a spectrometer the x-ray tube irradiates a large amount of an element whose characteristic x rays have a slightly higher energy than the absorption edge of the element being determined in the sample. The sample is then irradiated with these x rays. The principal advantage of this approach is that interchangeable secondary sources allow the energy of the incident x rays to be optimized for efficient excitation and hence, high detection sensitivity. The background radiation in the energy range of interest is also orders of magnitude lower than that in the direct irradiation method. The principal disadvantage of the secondary source excitation is that a high power x-ray tube and generator are required.

In this work a secondary source of 0.010-inch thick holmium foil was irradiated by an x-ray tube operated at 75 keV and 19 mA. The typical assay time was 200 sec. The energy of the holmium x rays (47.5 keV) limited our measurements to elements with atomic numbers less than or equal to 62 (samarium). The holmium x radiation was passed through a copper collimator prior to striking the sample in order to reduce the irradiation of the sample support, chamber walls, etc. Similarly, the Si(Li) x-ray detector (which has a 185 eV resolution for the manganese K_α x ray) viewed the emitted fluorescence through a copper collimator to minimize detection of scattered background radiation. A detailed description of the apparatus has been given elsewhere.[1]

In the application of XRF to our specific circumstances, several questions immediately arose: (1) could our apparatus resolve the K_α peak of rare earth element Z from the K_α peaks of the Z-1 and Z+1 elements as well as K_β peaks from element Z-3, and (2) would the different matrices provided by the dust particles on the air filter samples give rise to varying x-ray attenution?

The x-ray spectrum from a filter with an evaporated solution containing lanthanum, cerium, praseodymium and neodymium revealed distinctly separated K_α

peaks, each with a shoulder due to fine structure splitting. The Nd K_α peak (37.36 keV) was slightly overlapped by the La K_β peak (37.80 keV). The amount of La K_β intensity to subtract from the composite peak was obtained by measuring the intensity ratio K_β/K_α in a pure lanthanum spectrum and multiplying the La K_α intensity in the mixed rare earth sample by this ratio. A typical mixed lanthanide spectrum is shown in Figure 2.

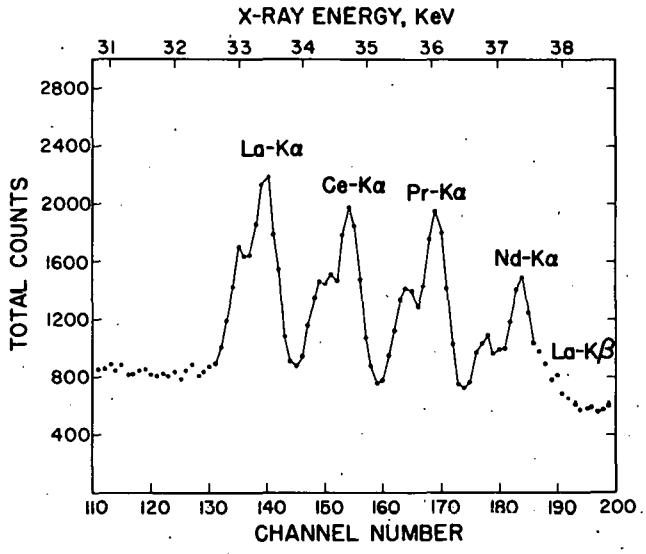

FIG. 2.--X-ray spectrum from 8 µg each of La, Ce, Pr, and Nd (200 sec irradiation).

A series of spectra for samples of mixtures of the lanthanides containing amounts of each lanthanide ranging from 5 to 50 µg showed that up to about 30 µg of a lanthanide in a mixture could be present without causing serious deviations from linearity of the net intensity versus concentration curve. To test the importance of matrix effects, two air filter samples, one with a light dust deposit (typically 1.00 to 1.80 mg/cm^2), the other with a heavy one (typically 1.80 to 2.65 mg/cm^2), were examined. Four sections of each filter were spiked with the addition of a series of 5 µL aliquots of a premixed lanthanide solution which contained 1.0 µg/µL of each lanthanide. That is, additions of 5, 10, 15, and 20 µg were made and compared to a filter with no dust. Background intensities were determined by drawing straight baselines between the low points on either side of each peak and summing the intensities beneath these baselines and between the channels (on the multichannel analyzer) which defined each peak. These background intensities were

subtracted from the total intensities under the peaks to obtain the net peak intensities. The lines of net peak intensity versus concentration of the spiked air filter samples were parallel to those of each corresponding lanthanide on the clean filter, as shown for Ce data in Figure 3. This demonstrated that there was negligible x-ray attenuation due to the dust and paper matrices of the air filter samples and that this effect would not pose a problem in their analyses.

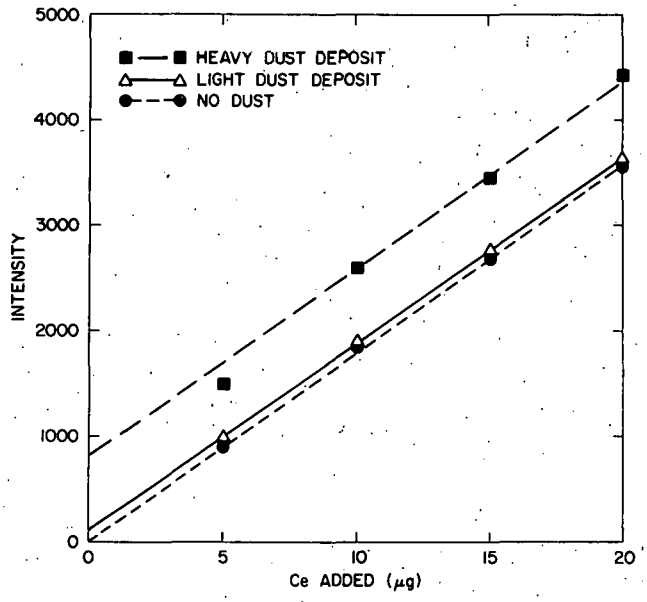

FIG. 3.--Ce peak intensity vs. amount (μg) of Ce added to each of three filters.

Because the dust deposit (~ 1" diameter) was rarely centered on the 1 ¼" diameter Whatman filters, and further, because the intensity of the exciting holmium x rays was not uniform over such a relatively large area, the actual samples used for analysis were disks 0.82 cm in diameter punched from the central dust area on the filters. These were mounted with epoxy adhesive on cross-hair threads of Teflon, which were supported in a standard 2" by 2" photographic slide mount. The 0.82 cm diameter disks represented 0.104 of the total area of the dust deposit. With this arrangement, the reproducibility of the results was generally ± 5%. This obviated the need for standard addition techniques or the use of internal standards.

Quantitative results were obtained with standard calibration curves of net peak intensity versus concentration. Premixed solution standards, each containing 1.0 to 10.0 μg of La, Ce, Pr, or Nd were measured twice. It was empirically determined that low solution volumes (≤5 μL) yielded more consistent results. The average net intensities were used to plot the calibration curve for each of these four lanthanides. For example, the neodymium calibration curve is shown in Figure 4. The rare earth detection

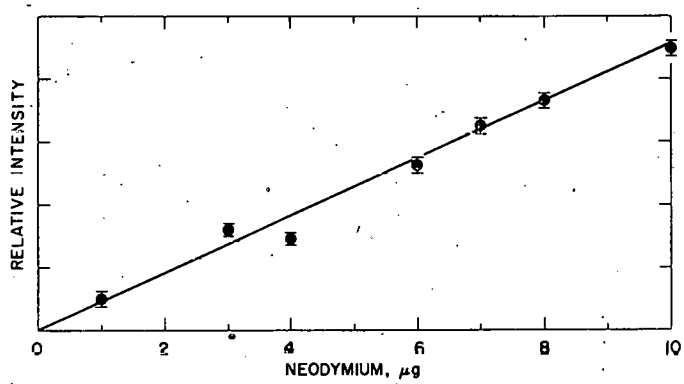

FIG. 4.--Calibration curve for Nd relating the observed peak intensity to the amount present on the filter.

limit for the 0.82 cm filter disks was approximately 100 ng, corresponding to 1 μg for the entire filter. Chemical concentration of the rare earths and redeposition of the entire amount onto a 0.82 cm filter disk would have increased the sensitivity to about 100 ng for an entire filter. This procedure was not necessary for our samples. A large excess of one element (e.g., 200-fold) does not seriously affect the accuracy of determining a neighboring element. However, because of the partial overlap of the La K_β peak with the Nd K_α peak, a large La/Nd ratio does increase the uncertainty of the Nd measurement.

Results

Fourteen air filter samples, accumulated in 1967 and 1970, were analyzed. Typically La, Ce, Pr, and Nd were detected, but never Sm. The relative amounts were usually in the order La ≅ Ce > Nd > Pr. The amounts (whole filter) ranged from 7 to 54, 4 to 108, 5 to 52, and 4 to 12 μg for La, Ce, Nd,

Table 1. Rare earth content in collected dusts

Air filter No.	Concentration, μg/filter ± SE (n = 2)			
	La	Ce	Pr	Nd
530	15.5 ± 2.1	10.4 ± 2.1	4.7 ± 2.1	16.0 ± 2.7
601	53.8 ± 2.6	107.7 ± 5.0	11.6 ± 1.9	51.6 ± 4.5
620	11.6 ± 1.6	7.8 ± 2.3	6.8 ± 3.3	5.0 ± 2.2
633	9.1 ± 1.3	7.4 ± 1.3	a	11.2 ± 4.3
639	48.6 ± 2.4	71.3 ± 3.6	5.6 ± 1.7	44.6 ± 4.0
852	18.8 ± 1.7	15.5 ± 1.7	7.1 ± 1.7	13.5 ± 2.8
665	10.2 ± 1.6	a	a	a
688	25.7 ± 1.7	22.2 ± 1.9	6.8 ± 1.7	11.6 ± 2.3
56	10.0 ± 1.4	a	6.4 ± 1.8	6.4 ± 2.2
48	10.6 ± 1.2	10.3 ± 1.4	4.2 ± 1.4	8.0 ± 1.8
1283	8.7 ± 1.1	4.1 ± 1.1	4.9 ± 1.3	8.5 ± 1.8
143	7.7 ± 1.1	3.8 ± 1.4	a	9.3 ± 2.3
64	13.6 ± 1.7	4.6 ± 1.3	a	15.5 ± 2.7
82	10.9 ± 1.0	10.4 ± 1.5	5.0 ± 1.4	18.6 ± 3.2
Mean ± SE	18.2 ± 4.0	23.0 ± 9.4	6.3 ± 0.7	16.9 ± 4.0
Geom. mean (SE_g)[b]	14.7(1.2)	12.3(1.4)	6.1(1.1)	13.2(1.3)

[a]No detectable concentration (< 1 μg/filter).

[b]Geometric standard error ($\times / \div SE_g$).

and Pr, respectively, as summarized in Table 1. These amounts correspond to the respective airborne concentrations of 44 to 340, 25 to 680, 32 to 328, and 25 to 76 ng/L. By comparison, typical concentrations of these elements in urban aerosols are 0.005, 0.01, 0.006, and 0.003 ng/L, respectively.[2] The rare earth content of the filters did not correlate with thorium radioactivity levels. This probably implies that different types of dusts were collected on the filters; that is, they were dust deposits of intermediate products or separated chemicals rather than monazite ore containing thorium and rare earths. On the other hand, certain lanthanide concentrations did correlate well with each other. For example, there were significant correlations between the La and Ce concentrations ($r = 0.97$, $P < 0.01$, $n = 12$) and between those for Nd and La ($r = 0.94$, $P < 0.01$, $n = 14$). That between Pr and Ce was weaker ($r = 0.76$, $P \cong 0.01$, $n = 10$), and that between Nd and Pr was not significant ($r = 0.58$, $P > 0.05$, $n = 10$). The arithmetic and geometric means and their standard errors have been included in Table 1 to indicate that the variations of the lanthanide concentrations among the samples were reasonably small, despite the fact that the samples were collected in different places within the plant and over a time span of three years.

Thus, we have established the utility of x-ray fluorescence spectrometry for rare earth aerosol analysis. XRF has been demonstrated to be rapid, devoid of any complicated and time-consuming steps in procedure or calculation, and reliable within statistically acceptable limits for the levels of concentration examined.

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MEASUREMENTS OF ^{202}Tl IN VIVO*

R. E. Toohey, M. A. Essling, J. Y. Sha, and P. W. Urnezis

In our low-background counting facilities, we can routinely measure the γ-ray emission from as little as a few tenths of a nanocurie of radioactivity in vivo. Consequently we can determine the retention and distribution of injected radiopharmaceuticals for extended periods of time post-administration. Since the metabolic behavior of these isotopes may vary with time, such information is required to compute accurately the radiation dose received by the patient. In this paper we report measurements in vivo of the 440-keV γ-ray emitted by ^{202}Tl (physical half-life 12.2 days). This isotope is a contaminant commonly present at a level of about 1% in cyclotron-produced ^{201}Tl (physical half-life 3.0 days), which is injected as thallous chloride for nuclear cardiology studies.[1]

Figure 1 shows the whole-body content of ^{202}Tl of case no. 30-202. The observed effective half-life of 6.14 ± 0.04 days corresponds to a biological half-life of 12.4 ± 0.1 days, which falls within the range of 7.4 - 12.4 days (mean 9.8 days) reported by other workers in a study of ^{201}Tl retention by four patients over a period of two weeks.[2] The important aspect of our data is that no additional component in the retention curve was observed for a period five times longer. No short-lived components were observed in the previous work,[2] and from our data we can deduce an upper limit of 0.05% of the injected dose as the amount which could possibly be retained with a longer biological half-life.

The distribution of ^{202}Tl in the body was determined by making profile scans with a slit-collimated detector. In general, ^{202}Tl was observed in skeletal muscle and the viscera, as expected for a potassium analogue.[1] No changes in the distribution were noted between scans made on days 3 and 21 post-injection.

The excretion rate of ^{201}Tl and the ratio of ^{202}Tl to ^{201}Tl were determined by analyzing 24-hour urine and fecal samples for γ-ray activity with a Ge(Li) detector in a standardized geometry. On day 15 post-injection,

*Summary of a paper presented at the 26th Annual Meeting of the Health Physics Society, Louisville, KY, June 21-25, 1981.

the urinary excretion was 1.5% of the body content, while the fecal excretion was 3.9%. The total, 5.4%, was in excellent agreement with the excretion rate of 5.6%/day predicted by the whole-body retention curve obtained for ^{202}Tl (Figure 1). However, previous workers had assumed that fecal excretion is

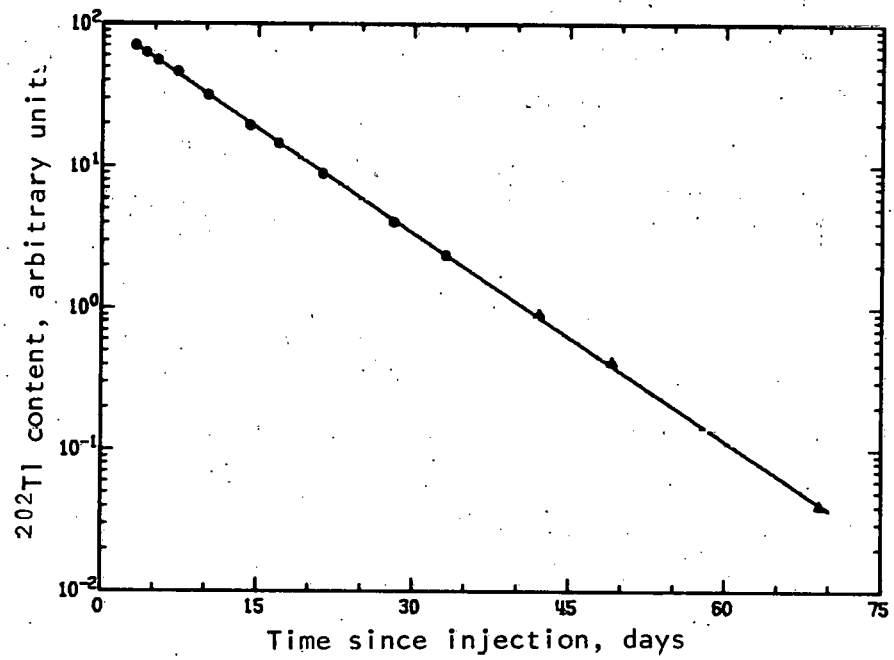

FIG. 1.--The whole-body content of ^{202}Tl of case 30-202. Circles represent the results of γ-ray measurements made with the subject in a 1.5-m arc geometry, while triangles represent those made in the reclining chair. The solid line is a single exponential function with an effective half-life of 6.14 d. Since the physical half-life is 12.2 d, the biological half-life is, therefore, 12.4 d.

negligible.[2] Our findings refute this assumption and imply that the radiation dose from ^{201}Tl received by the intestinal tract may be underestimated, and the dose to the bladder over-estimated, even though the whole-body dose may not be affected.

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APPENDIX A. Exposure Data for Radium Patients

Table 1 summarizes exposure data collected as of 31 December 1980 for 2259 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 1980 annual report[1] listed 2223 cases. The radium burdens of 34 persons were measured for the first time in 1980, and two cases not previously listed were added because reports of measurements made in prior years were located. Each of the 36 additional cases is identified by a star following the year of measurement. There were follow-up examinations and burden measurements in 1980 on 64 previously listed persons. Changes in basic data for several of the previously listed cases are due to review of information on exposure histories and to reassessment of old measurement data.

The cases are listed in order of identification number. In column 5, the type of exposure to radium (dial painting, medical, etc.) is indicated by code digits, which are defined in Table A1; if more than one type of exposure occurred, two non-zero digits are given. Column 7 gives the total period (in weeks) from first to last exposure. A value of 0 means that the exposure was a single event or had a duration of less than one week. However, "+0" means that the duration of exposure is unknown (a single exposure or longer); in these cases, zero duration was used in the calculation of the dose. For a dial painter whose first exposure was before the year 1926 but whose period of exposure extended into 1926 or beyond, the duration used in calculating the dose corresponds to the exposure terminating in 1926.

The ^{226}Ra body burdens given in the table are expressed as nanocuries (nCi) of ^{226}Ra present in the year of measurement shown in the preceding column. If several measurements over a period of years had been made for a given case, the result (and date) of the last measurement of highest available quality is given. Under "METHOD + ERR," the first symbol indicates the type of measurement according to the letter code of Table A2. Type A indicates

that a complete skeletal measurement of bones was made; the letters B, C,..., G tend to imply increasingly uncertain types of measurement, but with wide variation in size of error within each category. The digit that follows the method letter is the code symbol for an error estimated on the basis of type of measurement, amount of radium found, and examination of the data reported by the contributing laboratories. Code definitions for size of error are given in Table A3, and the errors shown include systematic errors as well as replication errors.

The letter L in place of a digit in the error column indicates that the result was taken from the New Jersey Radium Research Project records in which the measured value of ^{226}Ra was less than 4 nCi, their reported lower limit of detection. For these cases, the value of 4 is shown in the ^{226}Ra column, but the letter L means that the 90% confidence limits extend from 0.0 nCi to an upper limit somewhere between 4 and 8 nCi. There are 53 of these cases which have the prefix 05 in the case number and one with case number 01-222. A "less than" indication was not used for cases measured at the other sites, even though the best measurements of small whole-body burdens have a standard deviation of 1 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 burdens.

The entries in column 11 are activity ratios of ^{228}Ra to ^{226}Ra at the time of measurement of ^{226}Ra body content. A value of 5.7 yr for the half-life of ^{228}Ra was used in making corrections for radioactive decay. The method and error designations in column 12 are defined in Tables A2 and A3. The letter Z for method means that the ratio for the indicated person was estimated from values obtained on a group of persons with similar exposure histories or from analysis of samples of the radium material to which the person was exposed.[2] If no direct measurement of ^{228}Ra was attempted, only the letter Z and the error designation are shown. If measurement of ^{228}Ra was attempted, the method tried is indicated by the letter after the error symbol in column 12. Ratios obtained by measurements of ^{228}Ra and ^{226}Ra are indicated by a letter other than Z. In all cases, the error designations in column 12 refer to the ratios in column 11. Errors for ratios with method codes of Z or F do not include errors in the measured values of ^{226}Ra body content.

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

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

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

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

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

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

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

[b] Ref. 2

The last four columns of Table 1 give quantities calculated from the measured body burdens and exposure data shown in the other columns. For many cases, the number of significant digits shown obviously exceeds the number justified by the accuracy of the basic data, and the errors indicated for the latter should be applied to the derived quantities. The columns under "INPUT" give the amounts of initially acquired ^{226}Ra and ^{228}Ra expressed as microcuries (μCi), calculated by applying the Norris retention function[3] to values of body burdens usually measured long after the initial intake. The cumulative rads, given in the last two columns for ^{226}Ra and ^{228}Ra separately, refer to the average absorbed dose to the skeleton[4] -- either up to the date of death or, for the living subjects, through 1980. 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 1 EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	1889	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	78	0
00-033	M	1868	1922	06	1919	156	1970	6	A6	0.00300	Z7A	0	0	0	0
00-034	F	1882	1943	06	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	0.02150	F1	2599	236	16586	3220
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
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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	0.02958	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	29	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	27	24
01-039	F	1915		07	1934	1092	1972	1	B6	0.0	Z9B	0	0	2	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	31	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	321	2048
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	1957	150	B2	0.13330	D5	36	251	519	3781
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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	364	1709
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	Z9B	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	459	2255
01-081	F	1907		01	1923	11	1959	7	B6	0.08000	Z2B	2	11	27	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	206	1110
01-085	F	1913		01	1927	47	1958	6	B6	0.02200	Z8B	1	1	20	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	21	19
01-091	F	1907		01	1927	264	1979	0	B6	0.00179	Z8B	0	0	0	0
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	87	64
01-097	F	1905		01	1921	110	1963	122	B1	0.03852	B2	33	187	508	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	5	5
01-112	F	1908	1955	01	1924	835	1960	80	F4	0.07000	F1	19	92	185	1368
01-113	F	1912		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	36	44
01-122	F	1912		01	1927	49	1978	8	B3	0.00202	Z9B	2	2	35	35
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	Z9B	13	12	180	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	40	39
01-132	F	1908	1944	01	1923	76	1966	1327	A1	0.03496	A1	253	1505	1946	21690
01-133	F	1910		01	1926	65	1958	13	B2	0.03000	Z8B	3	4	45	64
01-136	F	1907		01	1923	185	1978	30	B1	0.00674	B3	9	42	140	638
01-137	F	1901		01	1923	714	1977	5	B3	0.00902	Z2B	2	8	23	125
01-138	F	1883	1963	04	1919	4	1959	10	G6	0.0	Z9	3	0	34	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	1974	17	B2	0.00330	Z5B	5	4	47	40
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	247	0
01-148	F	1907		06	1936	364	1958	40	G4	0.0	Z9	7	0	87	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
01-151	F	1905		06	1927	52	1976	1	B6	0.0	Z9	0	0	3	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		02	1925	13	1975	49	B2	0.00139	Z5B	15	9	218	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		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	1978	14	C3	0.0	Z9C	4	0	66	0
01-166	F	1897	1969	01	1916	26	1959	0	B6	0.0	Z9B	0	0	0	0
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	4	G6	0.0	Z9	1	0	5	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	1959	70	G4	0.0	Z9	16	0	110	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	123	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	33	0
01-187	M	1917		06	1943	78	1980	23	C2	0.0	Z9C	6	0	46	0
01-188	F	1886	1979	04	1933	3	1959	4	G6	0.0	Z9	1	0	11	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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		01	1916	576	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	188	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
01-201	F	1911		01	1925	55	1959	26	B2	0.02100	Z8B	6	8	94	119
01-203	F	1908		01	1923	1	1973	0	B6	0.01470	Z2B	0	0	0	0
01-204	F	1901		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		06	1918	17	1975	9	B2	0.0	Z9B	3	0	33	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
01-214	M	1891	1964	06	1915	1248	1959	82	B1	0.00700	Z7B	19	4	156	47
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	7	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	25	27
01-229	F	1903		01	1923	2	1959	8	B2	0.08000	Z2B	2	13	31	196
01-230	F	1913		01	1927	19	1978	0	B6	0.00203	Z8B	0	0	0	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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
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	28	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	1976	5	B3	0.00195	Z7B	1	1	14	8
01-248	F	1903		01	1917	208	1976	21	B2	0.0	Z9B	7	0	107	0
01-249	M	1928		08	1928	39	1967	2	G6	0.02700	Z2	1	2	5	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	115	0
01-253	F	1898	1964	01	1916	104	1959	40	G6	0.0	Z9	11	0	147	0
01-254	F	1910		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		06	1949	208	1959	14	G6	0.0	Z9	2	0	11	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	40	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	15	G6	0.0	Z9	4	0	50	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	107	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	172	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
01-268	F	1901	1968	01	1920	48	1967	100	B2	0.01000	B2	29	84	391	1264
01-269	M	1911		06	1932	524	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	11	0
01-271	F	1899		01	1917	86	1979	2	B6	0.0	Z9B	1	0	11	0
01-272	M	1888		06	1956	130	1959	78	G6	0.0	Z9	4	0	23	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	60	G6	0.0	Z9	9	0	39	0
01-277	F	1909		01	1925	6	1978	5	C6	0.00828	Z2	1	7	21	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	7	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	12	11
01-295	F	1910		01	1927	14	1976	0	B6	0.00258	Z8B	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	64	589
01-299	F	1896		01	1917	104	1968	3	G6	0.0	Z9	1	0	14	0
01-301	F	1904		05	1926	5	1969	17	G4	0.0	Z9	5	0	69	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	24	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 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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		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	120	0
01-331	M	1901		02	1927	+0	1966	80	G4	0.01100	Z5	21	27	219	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	1976	0	B6	0.01075	Z2	0	0	0	0
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	51	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	159	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		06	1940	338	1962	191	B1	0.0	Z9B	35	0	280	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	94	460
01-360	F	1911		01	1928	34	1962	0	G6	0.01400	Z8	0	0	0	0
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	20	13

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
01-365	F	1901		01	1924	40	1962	10	G6	0.05700	Z2	3	15	39	218
01-367	F	1899		01	1920	221	1976	4	B6	0.01024	Z2B	1	9	19	135
01-368	M	1925		06	1947	65	1979	35	B1	0.0	Z9B	8	0	62	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	43	47
01-376	F	1907	1973	01	1927	33	1963	2	G6	0.01300	Z8	1	1	7	8
01-377	F	1915		17	1929	208	1979	1	B6	0.0	Z9B	0	0	4	0
01-378	F	1907		01	1925	94	1976	0	B6	0.00258	Z8B	0	0	0	0
01-379	F	1909		01	1926	7	1975	18	B2	0.00281	Z8B	5	6	78	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	175	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	33	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	1972	4	B3	0.0	Z9B	1	0	6	0
01-395	F	1945		07	1950	520	1972	5	B3	0.0	Z9B	1	0	8	0
01-396	M	1947		07	1950	520	1972	1	B6	0.0	Z9B	0	0	1	0
01-397	F	1950		07	1950	498	1973	4	B3	0.0	Z9B	1	0	6	0
01-398	M	1951		07	1951	429	1972	0	B6	0.0	Z9B	0	0	0	0
01-399	F	1953		07	1953	350	1972	1	B6	0.0	Z9B	0	0	1	0
01-400	M	1903		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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
01-403	F	1912		02	1926	+0	1971	27	B2	0.01838	C3	8	34	114	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	47	0
01-409	F	1914		06	1930	13	1975	34	B3	0.0	Z9B	10	0	135	0
01-410	F	1920		06	1940	156	1978	33	B1	0.0	Z9B	9	0	99	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	36	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	74	0
01-424	F	1882	1979	05	1924	+0	1964	280	G4	0.0	Z9	76	0	1114	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
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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	35	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	98	131
01-449	F	1899		01	1922	2	1965	7	G6	0.03900	Z2	2	14	30	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	0.0		586	0	7760	0
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	35	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	16	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	13	0
01-470	F	1912		01	1927	70	1965	0	G6	0.01000	Z8	0	0	0	0
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		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	144	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	4	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	798	637

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	9	0
01-497	F	1902	1978	01	1921	8	1966	13	G6	0.03400	Z2	4	30	56	451
01-498	F	1897		06	1920	104	1976	1	B6	0.0	Z9C	0	0	5	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	34	37
01-506	F	1897		04	1923	4	1966	7	B3	0.0	Z9C	2	0	30	0
01-507	F	1909		01	1927	22	1974	10	B2	0.00313	Z8B	3	3	42	41
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	145	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	1975	0	B6	0.00200	Z5B	0	0	0	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	25	0
01-520	F	1882	1969	02	1930	+0	1967	670	B1	0.00492	B2	174	77	2044	1158
01-521	M	1910		06	1942	520	1979	21	B2	0.0	Z9B	5	0	38	0
01-522	M	1905		06	1928	2288	1979	169	C2	0.0	Z9B	35	0	243	0
01-523	M	1917		06	1942	312	1968	30	G4	0.0	Z9	6	0	47	0
01-525	M	1923		06	1943	104	1968	17	G6	0.0	Z9	4	0	28	0
01-526	M	1921		06	1945	38	1979	29	B1	0.0	Z9B	7	0	56	0
01-529	M	1920		06	1943	260	1975	14	B2	0.0	Z9B	3	0	25	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	24	0
01-532	M	1914	1973	06	1945	138	1968	1	G6	0.0	Z9	0	0	1	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	26	0
01-537	M	1917	1971	06	1944	208	1968	59	B1	0.0	Z9B	12	0	74	0
01-540	M	1890		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	20	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	42	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	296	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	0.00730	Z8	0	0	0	0
01-557	F	1908		01	1925	35	1975	2	B6	0.00293	Z8B	1	1	9	11
01-558	M	1913		02	1927	130	1979	313	B1	0.00053	B2	96	24	967	262
01-562	F	1901	1931	01	1920	52	1970	10300	A1	0.0	Z9A	1392	0	7143	0
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	38	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	224	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	15	0
01-582	F	1893		06	1917	24	1979	1	B6	0.0	Z9B	0	0	5	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	18	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	24	0
01-597	F	1923		01	1940	364	1973	1	B6	0.0	Z9C	0	0	3	0
01-598	M	1879	1953	06	1941	572	1952	400	G6	0.0	Z9	27	0	71	0
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	32	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	Z9C	3	14	38	214
01-625	F	1911		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	145	143
01-653	F	1910		01	1925	78	1969	7	G6	0.00420	Z5	2	2	29	25

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
01-659	F	1912		01	1928	26	1969	11	G6	0.0	Z9	3	0	42	0
01-660	F	1881	1957	04	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	31	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
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		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
01-728	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	195	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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
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	3308	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	2800	0
03-116	F	1907		05	1931	25	1973	1411	B1	0.0	Z9C	391	0	5304	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	1908		05	1931	10	1931	6500	E4	0.0	Z9	92	0	892	0
03-123	M	1914	1937	05	1931	9	1931	9700	B2	0.0	Z9	139	0	361	0
03-124	M	1910		05	1931	9	1980	189	C2	0.0	Z9C	57	0	553	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	1811	0
03-135	M	1905		05	1931	+0	1973	1431	B1	0.0	Z9C	398	0	3866	0
03-139	M	1908		05	1933	11	1973	373	C2	0.0	Z9C	101	0	953	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	4771	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
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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	28	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	10	0
03-219	F	1888	1961	04	1919	+0	1951	60	B2	0.0	Z9	14	0	178	0
03-220	M	1920		04	1928	208	1976	130	B1	0.0	Z9C	38	0	372	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	84	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		05	1927	+0	1976	438	B1	0.0	Z9C	132	0	1888	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	11	0
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		01	1923	260	1974	1223	B1	0.00010	F2	370	15	5467	220
03-403	F	1915	1964	01	1935	572	1957	8	C3	0.0	Z9	1	0	11	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
03-404	F	1897		01	1923	195	1975	577	B1	0.0	Z9C	177	0	2606	0
03-405	F	1904		16	1924	273	1962	625	C2	0.0	Z9	159	0	2285	0
03-406	F	1914		01	1935	484	1980	3	C6	0.0	Z9C	1	0	11	0
03-407	F	1905	1961	01	1923	1196	1958	1545	B1	0.00022	F2	382	5	4286	73
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	22	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		01	1922	134	1977	227	B2	0.0	Z9C	72	0	1075	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	5	0
03-415	F	1911	1973	01	1930	780	1957	15	C3	0.0	Z9	3	0	30	0
03-416	F	1907		01	1923	65	1979	1075	C2	0.0	Z9C	345	0	5145	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	2593	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	1978	10	C1	0.0	Z9C	3	0	46	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	1140	0
03-425	F	1916		01	1935	293	1980	3	C6	0.0	Z9C	1	0	9	0
03-426	F	1906		01	1924	2184	1979	131	C2	0.0	Z9C	41	0	608	0
03-427	F	1906		01	1925	823	1973	12	B2	0.0	Z9C	4	0	54	0
03-428	F	1908		01	1925	164	1974	493	B1	0.0	Z9C	148	0	2153	0
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	10	0
03-431	F	1901		01	1922	156	1963	1297	C2	0.0	Z9	349	0	5216	0
03-432	F	1902		01	1923	112	1980	23	C2	0.0	Z9C	8	0	112	0
03-433	F	1904		01	1924	117	1964	1052	C2	0.0	Z9	281	0	4130	0
03-434	F	1920		01	1941	125	1975	5	B2	0.0	Z9C	1	0	13	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	32	0
03-437	F	1906		01	1926	52	1957	55	C2	0.0	Z9	13	0	187	0
03-438	F	1908		01	1925	8	1957	0	C6	0.0	Z9	0	0	0	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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		01	1925	528	1957	56	C2	0.0	Z9	13	0	196	0
03-442	F	1904		01	1924	13	1976	4	B2	0.0	Z9	1	0	18	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	57	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	270	0
03-447	F	1906		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	35	0
03-451	F	1922		01	1940	524	1972	1	B6	0.0	Z9C	0	0	2	0
03-452	F	1909		06	1925	728	1977	13	B2	0.0	Z9C	4	0	51	0
03-453	F	1907		01	1924	8	1976	3	B2	0.0	Z9C	1	0	14	0
03-454	F	1914		06	1934	572	1958	48	C2	0.0	Z9	9	0	103	0
03-455	F	1906		01	1922	56	1975	491	B1	0.00054	F1	153	49	2313	738
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	2	0
03-458	F	1925		01	1946	1560	1976	33	B2	0.0	Z9C	4	0	27	0
03-459	F	1906	1980	01	1924	43	1976	774	B1	0.0	Z9C	239	0	3537	0
03-460	F	1905		01	1923	19	1977	4	C6	0.0	Z9C	1	0	18	0
03-461	F	1896		01	1922	6	1958	6	C3	0.0	Z9	2	0	23	0
03-462	F	1906		01	1922	2912	1980	225	C1	0.0	Z9C	73	0	1078	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	1976	5	B2	0.0	Z9	2	0	23	0
03-466	F	1904		01	1924	10	1976	2	B3	0.0	Z9C	1	0	8	0
03-467	F	1911		01	1926	416	1976	8	B2	0.0	Z9C	2	0	31	0
03-468	F	1903		01	1926	121	1958	29	C2	0.0	Z9	7	0	98	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		01	1926	91	1958	13	C3	0.0	Z9	3	0	44	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
03-474	F	1909		01	1925	21	1958	19	C2	0.0	Z9	5	0	68	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	1972	3	B3	0.0	Z9C	1	0	13	0
03-478	F	1907		01	1924	8	1958	5	C6	0.0	Z9	1	0	18	0
03-479	F	1908		01	1924	52	1978	28	C2	0.00012	F2	9	1	128	11
03-480	F	1909		01	1924	10	1980	0	C6	0.0	Z9C	0	0	0	0
03-481	F	1922		01	1942	481	1972	9	B2	0.0	Z9C	2	0	20	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	940	0
03-487	F	1907	1964	61	1924	676	1958	367	C2	0.0	Z9	90	0	1055	0
03-488	F	1907	1975	01	1922	26	1958	170	C2	0.0	Z9	43	0	621	0
03-489	F	1911	1964	01	1926	73	1958	120	C2	0.0	Z9	29	0	326	0
03-490	M	1904		07	1925	177	1973	5	B3	0.0	Z9C	1	0	14	0
03-491	F	1908		01	1924	2	1979	19	C2	0.0	Z9C	6	0	89	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		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	1976	1	B6	0.0	Z9C	0	0	3	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	858	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	23	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	1978	11	C3	0.0	Z9C	3	0	53	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	15	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
03-509	F	1907		01	1924	2548	1973	28	B1	0.0	Z9C	8	0	121	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	40	0
03-513	F	1908		01	1925	48	1974	73	B1	0.0	Z9	22	0	321	0
03-514	F	1909		01	1925	208	1959	26	C2	0.0	Z9	6	0	94	0
03-515	F	1908		01	1925	156	1959	11	C3	0.0	Z9	3	0	40	0
03-516	F	1911		01	1925	624	1976	7	B2	0.0	Z9C	2	0	33	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	18	0
03-519	F	1903		01	1924	8	1959	98	C2	0.0	Z9	25	0	367	0
03-520	F	1907		01	1925	780	1974	112	C2	0.0	Z9	33	0	487	0
03-521	F	1907	1961	01	1925	39	1959	10	C3	0.0	Z9	2	0	27	0
03-522	F	1898		01	1921	52	1980	89	C2	0.0	Z9C	29	0	449	0
03-523	F	1900		01	1923	30	1980	8	C3	0.0	Z9C	2	0	36	0
03-524	F	1903		01	1925	260	1972	48	B2	0.0	Z9C	14	0	204	0
03-525	F	1911	1976	01	1931	2132	1959	19	C2	0.0	Z9	3	0	25	0
03-526	F	1896		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	18	0
03-528	F	1904		01	1922	524	1959	1630	C2	0.0	Z9	412	0	6118	0
03-529	F	1902		01	1921	104	1980	73	C2	0.0	Z9C	24	0	363	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	148	0
03-532	F	1910		01	1926	190	1980	44	C2	0.0	Z9C	14	0	193	0
03-533	F	1908		01	1925	260	1979	12	C3	0.0	Z9C	4	0	54	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	954	0
03-536	F	1910		01	1925	7	1959	35	C2	0.0	Z9	9	0	128	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	23	0
03-540	F	1904		01	1923	364	1973	1605	B1	0.0	Z9C	481	0	7098	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	1978	23	C2	0.0	Z9C	7	0	111	0
03-543	F	1918		01	1947	100	1972	1	B6	0.0	Z9C	0	0	3	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
03-544	F	1906	1975	01	1922	26	1959	5	C3	0.0	Z9	1	0	19	0
03-545	F	1898		01	1920	208	1959	0	C6	0.0	Z9	0	0	0	0
03-546	F	1903		01	1925	52	1959	95	C2	0.0	Z9	23	0	343	0
03-547	F	1907	1962	01	1923	108	1959	19	C2	0.00370	F2	5	1	55	19
03-548	F	1906		01	1922	17	1971	80	B1	0.0	Z9C	24	0	365	0
03-549	F	1910		01	1925	936	1980	41	C2	0.0	Z9C	13	0	191	0
03-550	F	1900		01	1917	104	1980	8	C3	0.0	Z9C	3	0	44	0
03-551	F	1903		01	1922	338	1973	1077	C2	0.0	Z9C	324	0	4816	0
03-552	F	1904		01	1924	108	1978	114	C2	0.0	Z9C	36	0	527	0
03-553	F	1904		01	1924	13	1979	6	C6	0.0	Z9C	2	0	30	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	1930	260	1972	2	B6	0.0	Z9C	1	0	8	0
03-556	F	1911		01	1928	100	1976	2	B3	0.0	Z9C	1	0	9	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	245	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	21	0
03-564	F	1906		01	1923	3	1976	3	B2	0.0	Z9C	1	0	16	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	7	0
03-567	F	1900		01	1922	104	1972	26	B2	0.0	Z9C	8	0	116	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	1976	8	B2	0.0	Z9C	3	0	37	0
03-571	F	1909		01	1925	52	1979	710	C2	0.0	Z9C	224	0	3264	0
03-572	F	1906		01	1924	56	1977	62	C2	0.0	Z9C	19	0	287	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	1976	4	B2	0.0	Z9C	1	0	17	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	118	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	51	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		01	1918	260	1966	74	C2	0.0	Z9	21	0	331	0
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	47	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		01	1922	26	1965	104	C2	0.0	Z9	29	0	442	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	341	0
03-593	F	1905		01	1922	10	1977	10	C3	0.0	Z9C	3	0	47	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	51	0
03-597	F	1903		16	1925	1300	1972	74	B1	0.0	Z9C	18	0	226	0
03-598	M	1890		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	624	1976	2	B3	0.0	Z9C	1	0	10	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	8	0
03-607	F	1906		01	1922	26	1980	97	C2	0.0	Z9C	32	0	481	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	424	0
03-615	F	1905		01	1923	107	1975	14	B1	0.0	Z9	4	0	65	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
03-617	F	1902	1951	01	1921	312	1963	7000	F4	0.0	Z9	1560	0	14586	0
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	0.00144	F1	425	76	5041	1143
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	9	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	1976	1	B6	0.0	Z9C	0	0	2	0
03-626	F	1906		01	1924	208	1960	200	G4	0.0	Z9	51	0	742	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	83	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	76	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	174	0
03-636	F	1904		01	1924	192	1976	5	B2	0.0	Z9C	2	0	24	0
03-637	F	1906		01	1924	6	1979	39	C2	0.0	Z9C	13	0	186	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	245	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	44	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	205	0
03-646	F	1888		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	130	0
03-648	F	1903	1956	01	1922	155	1956	5000	B2	0.00430	F2	1216	271	12670	4043
03-649	F	1906	1954	01	1924	1352	1951	1300	B2	0.0	Z9F	282	0	2725	0
03-666	F	1905	1929	01	1923	347	1978	24812	A1	0.00024	F2	2127	332	6560	2306
03-671	F	1906	1953	01	1922	8	1952	3820	B2	0.00500	F1	890	169	8980	2525
03-672	F	1899		01	1924	+0	1960	3	G6	0.0	Z9	1	0	11	0
03-673	F	1909		71	1926	8	1960	35	G6	0.0	Z9	9	0	126	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	1972	6	B3	0.0	Z9C	1	0	3	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	2	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	1977	1	B6	0.0	Z9C	0	0	6	0
03-685	F	1902		01	1921	65	1979	86	C2	0.0	Z9C	28	0	428	0
03-686	F	1904		01	1923	1040	1975	20	B2	0.0	Z9C	6	0	89	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	1980	71	C2	0.0	Z9C	23	0	337	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	9	0
03-695	F	1920		01	1942	34	1972	7	B3	0.0	Z9C	2	0	19	0
03-696	F	1932		01	1950	52	1963	0	C6	0.0	Z9	0	0	0	0
03-697	F	1902		01	1924	34	1967	181	C2	0.0	Z9	51	0	751	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		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	20	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
03-720	F	1910		01	1926	52	1976	6	B2	0.0	Z9C	2	0	24	0
03-722	F	1905		01	1924	4	1977	3	B2	0.0	Z9C	1	0	12	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	21	0
03-752	F	1904		01	1922	15	1980	7	C3	0.0	Z9C	2	0	35	0
03-753	F	1906		01	1922	+0	1980	12	C3	0.0	Z9C	4	0	62	0
03-757	F	1902		01	1923	91	1978	10	C6	0.0	Z9C	3	0	49	0
03-761	F	1901		01	1927	1144	1980	17	C3	0.0	Z9C	5	0	58	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	1976	2	B3	0.0	Z9C	1	0	9	0
03-771	F	1900		01	1923	13	1980	108	C2	0.0	Z9C	35	0	529	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	10	0
03-778	F	1904		01	1923	104	1973	54	B1	0.0	Z9C	16	0	243	0
03-779	F	1905	1942	01	1922	+0	1979	1835	A1	0.0	Z9	347	0	2651	0
03-782	F	1908		01	1923	5	1976	2	B3	0.0	Z9C	1	0	11	0
03-784	F	1905		01	1923	178	1954	750	C4	0.0	Z9	173	0	2561	0
03-788	F	1905		01	1926	104	1976	1	B6	0.0	Z9C	0	0	3	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	1976	2	B3	0.0	Z9C	1	0	10	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
03-818	F	1902		01	1927	62	1975	4	B3	0.0	Z9C	1	0	17	0
03-825	F	1906		01	1922	4	1976	1	B3	0.0	Z9C	0	0	5	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	5	0
03-842	F	1910		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	22	0
05-001	F	1900		01	1919	52	1978	43	B1	0.00039	Z7B	14	7	222	102
05-002	F	1903	1973	01	1917	104	1971	2	B6	0.0	Z9B	1	0	9	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	49	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	103	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		01	1917	52	1959	12	G6	0.0	Z9	3	0	53	0
05-012	F	1901	1959	01	1917	52	1970	16	A1	0.0	Z9A	4	0	54	0
05-014	F	1900		01	1916	208	1980	103	C2	0.00058	B6C	35	38	559	571
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	431	53
05-037	F	1898	1977	01	1916	260	1971	2	B6	0.0	Z9B	1	0	10	0
05-038	F	1901		07	1916	156	1972	99	G4	0.0	Z9	32	0	503	0
05-039	F	1899		07	1917	156	1980	18	C2	0.00043	Z7C	6	5	94	68
05-040	F	1899		01	1917	54	1971	10	B2	0.0	Z9B	3	0	50	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	25	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		01	1916	78	1971	13	B2	0.0	Z9B	4	0	66	0
05-092	F	1901		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	14	0
05-096	F	1901	1971	01	1918	26	1962	234	C2	0.00050	Z7C	66	7	949	102

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	18	30
05-101	F	1902		01	1924	6	1964	4	CL	0.00850	Z7C	1	1	16	18
05-102	F	1900		01	1915	364	1960	6	C6	0.00350	Z7C	2	1	26	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	18	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	46	46
05-120	F	1890		07	1919	6	1959	5	G6	0.00770	Z7	1	1	21	20
05-121	F	1906		01	1921	26	1980	8	B3	0.00117	Z7B	3	4	40	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
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	54	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		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	40	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	12	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	1919	+0	1978	670	F4	0.00082	F2	184	197	2227	2957
05-142	F	1904		01	1919	39	1960	11	G6	0.00680	Z7	3	3	47	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	27	27

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	60	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		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
05-185	F	1912		01	1941	208	1972	2	B6	0.0	Z9B	0	0	5	0
05-186	F	1922		01	1941	156	1972	1	B6	0.0	Z9B	0	0	3	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		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		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		01	1924	208	1961	4	CL	0.0	Z9C	1	0	15	0
05-206	F	1894		01	1922	52	1971	2	B6	0.00360	Z7B	1	1	9	12
05-207	M	1893		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	1920	78	1969	1410	A1	0.00198	A3	417	291	5536	4376
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		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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
05-259	F	1900		07	1917	52	1960	6	G6	0.0	Z9	2	0	27	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	1972	3	B3	0.0	Z9C	1	0	7	0
05-263	M	1883	1967	07	1919	104	1962	4	CL	0.00800	Z7C	1	1	11	16
05-264	M	1903		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
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	26	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	16	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	38	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
05-303	F	1894	1980	01	1917	2184	1977	1	C6	0.0	Z9	0	0	7	0
05-304	F	1897		01	1921	26	1962	4	CL	0.01100	Z7C	1	2	17	26
05-306	F	1903		01	1921	156	1976	3	B3	0.00195	Z7B	1	1	14	18
05-307	F	1920		01	1944	74	1972	0	B6	0.0	Z9B	0	0	0	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	76	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
05-351	F	1891		01	1917	30	1968	23	G6	0.0	Z9	7	0	113	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		06	1917	165	1973	73	B1	0.00060	Z7B	23	10	366	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		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		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	9	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	13	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	37	0
05-443	F	1922		07	1941	52	1972	3	B6	0.0	Z9B	1	0	8	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP. DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
05-444	M	1899	1963	06	1917	43	1961	4	CL	0.0	Z9C	1	0	11	0
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	10	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	22	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		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		01	1918	9	1970	15	G6	0.00018	Z7	5	0	74	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	5	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	169	95
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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
05-892	F	1904		01	1917	4	1968	70	G6	0.0	Z9	22	0	345	0
05-897	F	1899	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	9	0
05-911	M	1886		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		01	1918	39	1966	83	B1	0.00030	Z7C	25	2	390	36
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	339	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	1969	194	G4	0.0	Z9	60	0	966	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	39	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	20	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
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	90	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	40	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		01	1917	18	1975	0	B6	0.0	Z9B	0	0	0	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	86	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	1305	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		01	1915	+0	1969	14	G6	0.0	Z9	4	0	73	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	20	0
09-064	F	1891		01	1916	9	1973	1	B6	0.0	Z9B	0	0	5	0
09-065	F	1887	1975	06	1914	78	1960	1	B6	0.0	Z9B	0	0	5	0
09-066	F	1899		01	1917	8	1972	2	B6	0.0	Z9B	1	0	10	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		06	1916	570	1962	0	G6	0.0	Z9	0	0	0	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
09-080	M	1886		06	1919	312	1962	5	G6	0.0	Z9	1	0	15	0
09-082	M	1892		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	55	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
09-107	M	1897	1974	06	1913	104	1965	1	G6	0.0	Z9	0	0	3	0
09-108	M	1891		06	1915	104	1965	4	G6	0.0	Z9	1	0	14	0
09-109	M	1895		06	1914	104	1965	4	G6	0.0	Z9	1	0	14	0
09-110	M	1900		06	1914	52	1965	7	G6	0.0	Z9	2	0	25	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	20	0
09-118	F	1901		07	1921	+0	1970	50	G4	0.0	Z9	15	0	231	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	1971	0	B6	0.0	Z9B	0	0	0	0
10-008	F	1904		01	1918	13	1976	0	B6	0.00009	Z7B	0	0	0	0
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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	56	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	7	0
10-034	F	1919		01	1943	202	1973	9	B2	0.0	Z9C	2	0	22	0
10-035	F	1922		01	1942	689	1974	10	B2	0.0	Z9C	2	0	22	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	6	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
10-041	F	1924		01	1943	13	1972	1	B6	0.0	Z9C	0	0	2	0
10-042	F	1927		01	1947	130	1972	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		01	1948	13	1972	19	B2	0.0	Z9C	4	0	41	0
10-045	F	1923		01	1946	13	1972	1	B6	0.0	Z9C	0	0	2	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	27	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	104	1974	11	B2	0.0	Z9C	2	0	28	0
10-051	M	1914		06	1931	468	1979	1	C6	0.0	Z9C	0	0	3	0
10-053	F	1926		17	1946	260	1972	2	B6	0.0	Z9C	0	0	4	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	1972	6	B3	0.0	Z9C	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
10-061	F	1923		07	1942	164	1972	6	B3	0.0	Z9C	1	0	15	0
10-062	F	1920		01	1939	182	1972	1	B6	0.0	Z9C	0	0	3	0
10-063	F	1911		01	1928	624	1976	2	B3	0.0	Z9C	1	0	7	0
10-064	F	1921		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	18	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	9	0
10-070	F	1921		01	1945	1352	1974	14	B2	0.0	Z9C	2	0	16	0
10-071	F	1924		01	1943	1508	1972	13	B2	0.0	Z9C	1	0	11	0
10-072	F	1924		01	1947	1300	1972	12	B2	0.0	Z9C	1	0	9	0
10-073	M	1919		07	1953	208	1972	0	B6	0.0	Z9C	0	0	0	0
10-074	M	1921		06	1950	1508	1979	21	C3	0.0	Z9C	2	0	11	0
10-075	F	1929		01	1949	260	1972	5	B3	0.0	Z9C	1	0	10	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	26	0
10-079	F	1920		01	1940	624	1978	8	C3	0.0	Z9C	2	0	20	0
10-080	F	1913		76	1943	1508	1972	5	B3	0.0	Z9C	1	0	4	0
10-081	F	1916		01	1946	104	1980	3	C3	0.0	Z9C	1	0	8	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	7	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	260	1972	3	B6	0.0	Z9C	1	0	6	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	11	0
10-096	F	1930		01	1951	832	1972	0	B6	0.0	Z9C	0	0	0	0
10-097	F	1919		01	1943	364	1972	4	B3	0.0	Z9C	1	0	8	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
10-098	F	1917		01	1935	208	1972	4	B3	0.0	Z9C	1	0	12	0
10-099	F	1924		01	1942	104	1980	12	C3	0.0	Z9C	3	0	35	0
10-100	F	1924		76	1942	78	1972	7	B3	0.0	Z9C	2	0	19	0
10-101	F	1925		01	1943	208	1972	0	B6	0.0	Z9C	0	0	0	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	208	1972	2	B6	0.0	Z9C	0	0	5	0
10-105	F	1927		01	1946	260	1972	0	C6	0.0	Z9C	0	0	0	0
10-106	F	1926		01	1946	104	1972	2	C6	0.0	Z9C	0	0	5	0
10-107	F	1909		01	1926	9	1972	0	B6	0.0	Z9C	0	0	0	0
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	1976	7	B2	0.0	Z9C	2	0	33	0
10-112	M	1902		01	1923	+0	1976	3	B3	0.0	Z9C	1	0	10	0
10-113	F	1924		01	1942	52	1972	0	B6	0.0	Z9C	0	0	0	0
10-114	F	1937		01	1970	104	1972	1	B6	0.0	Z9C	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	1352	1972	23	B2	0.0	Z9C	3	0	23	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		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		01	1917	8	1975	1	B6	0.0	Z9B	0	0	5	0
10-126	F	1927		01	1946	13	1972	0	B6	0.0	Z9C	0	0	0	0
10-128	F	1923		01	1942	364	1972	6	B3	0.0	Z9C	1	0	15	0
10-129	F	1923		01	1942	269	1975	9	B2	0.0	Z9C	2	0	23	0
10-130	F	1922		01	1942	147	1978	11	C3	0.0	Z9C	3	0	32	0
10-131	F	1917		07	1941	260	1972	1	B6	0.0	Z9C	0	0	3	0
10-132	F	1929		07	1970	130	1972	0	B6	0.0	Z9C	0	0	0	0
10-133	F	1910		01	1941	1248	1976	5	B2	0.0	Z9C	1	0	9	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	17	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TC RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	7	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
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	13	0
10-146	F	1921		01	1940	364	1972	4	B3	0.0	Z9C	1	0	9	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	11	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	5	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	56	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	56	0
10-171	F	1924		01	1942	156	1974	3	B3	0.0	Z9C	1	0	7	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	19	0
10-181	F	1912		01	1931	287	1978	2	C6	0.0	Z9C	0	0	6	0
10-190	F	1921		01	1951	110	1972	3	B6	0.0	Z9C	1	0	5	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	7	0
10-193	F	1921		01	1941	104	1972	3	B6	0.0	Z9C	1	0	7	0
10-195	F	1920		17	1937	1560	1978	11	C3	0.0	Z9C	2	0	22	0
10-198	F	1920		01	1946	378	1977	8	B3	0.0	Z9C	2	0	19	0
10-201	F	1918		71	1946	1352	1972	9	B2	0.0	Z9C	1	0	7	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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
10-206	F	1924		01	1943	230	1972	6	B3	0.0	Z9C	1	0	15	0
10-207	F	1923		61	1942	208	1972	12	B2	0.0	Z9C	3	0	29	0
10-208	F	1922		01	1942	7	1972	1	B6	0.0	Z9C	0	0	2	0
10-209	F	1920		01	1942	69	1972	6	B3	0.0	Z9C	1	0	16	0
10-210	F	1909		01	1926	1040	1972	17	B2	0.0	Z9C	4	0	54	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	32	0
10-221	F	1917		01	1941	676	1973	1	B6	0.0	Z9B	0	0	2	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	1976	4	B2	0.0	Z9C	1	0	6	0
10-226	F	1923		01	1941	1612	1972	3	B6	0.0	Z9C	0	0	2	0
10-227	M	1912		71	1928	2548	1977	6	B2	0.0	Z9C	1	0	6	0
10-228	F	1912		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	1976	3	B6	0.0	Z9B	1	0	5	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	1972	0	B6	0.0	Z9C	0	0	1	0
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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
10-249	M	1943		07	1962	126	1973	1	B6	0.0	Z9C	0	0	0	0
10-250	F	1938		07	1956	30	1972	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	416	1972	4	B3	0.0	Z9C	1	0	12	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	104	1972	0	B6	0.0	Z9C	0	0	1	0
10-258	F	1923		01	1943	26	1972	3	B6	0.0	Z9C	1	0	7	0
10-260	F	1913		01	1928	52	1978	2	C6	0.0	Z9C	1	0	7	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	4	0
10-263	F	1921		01	1941	130	1972	2	B6	0.0	Z9B	0	0	5	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	19	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		71	1946	154	1973	1	B6	0.0	Z9C	0	0	1	0
10-278	F	1908		71	1929	1872	1976	2	B6	0.0	Z9C	0	0	3	0
10-279	F	1937		01	1955	728	1973	2	B6	0.0	Z9C	0	0	2	0
10-280	F	1904		07	1921	2132	1976	1	B6	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
10-287	F	1923		01	1944	2	1973	1	B6	0.0	Z9C	0	0	3	0
10-291	F	1916		01	1934	156	1973	4	B3	0.0	Z9C	1	0	14	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	17	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	1976	5	B2	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	4	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	4	0
10-313	F	1924		01	1942	202	1973	9	B3	0.0	Z9C	2	0	23	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	16	0
10-320	M	1918		07	1939	1352	1973	1	B6	0.0	Z9C	0	0	1	0
10-321	F	1910		01	1942	1456	1976	1	B6	0.0	Z9C	0	0	1	0
10-322	F	1904		07	1936	1092	1976	5	B2	0.0	Z9C	1	0	11	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
10-327	M	1953		71	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	1976	1	B6	0.0	Z9B	0	0	3	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	16	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	0	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	10	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		01	1941	104	1978	1	C6	0.0	Z9C	0	0	2	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	1976	4	B2	0.0	Z9C	1	0	10	0
10-378	F	1906		07	1946	520	1976	0	B6	0.0	Z9C	0	0	0	0
10-379	F	1917		01	1941	89	1980	20	C2	0.0	Z9C	5	0	62	0
10-381	F	1927		01	1946	27	1973	6	B3	0.0	Z9C	1	0	13	0
10-382	F	1923		01	1942	119	1973	5	B3	0.0	Z9C	1	0	14	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
10-389	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	8	0
10-392	F	1903		71	1932	520	1973	0	B6	0.0	Z9C	0	0	0	0
10-393	F	1907		01	1925	208	1976	5	B2	0.0	Z9C	2	0	24	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	1976	2	B3	0.0	Z9C	1	0	10	0
10-397	F	1927		01	1946	16	1973	1	B6	0.0	Z9C	0	0	2	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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		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	61	0
10-439	F	1925		01	1943	20	1973	2	B6	0.0	Z9C	0	0	5	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	147	0
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	10	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	10	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
10-461	M	1925		06	1948	1300	1973	10	B2	0.0	Z9C	1	0	5	0
10-462	M	1927		06	1951	1144	1973	8	B3	0.0	Z9C	1	0	4	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	7	0
10-472	F	1928		01	1947	12	1973	0	B6	0.0	Z9C	0	0	0	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	6	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
10-487	F	1924		01	1943	220	1973	0	B6	0.0	Z9C	0	0	0	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	21	0
10-492	F	1925		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	4	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	13	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	4	0
10-532	F	1916		01	1942	2	1973	1	B6	0.0	Z9C	0	0	3	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TC RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	11	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	12	0
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	+0	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	3	0
10-575	F	1930		01	1948	1040	1973	4	B3	0.0	Z9C	1	0	5	0
10-579	M	1926	1979	07	1948	1248	1973	0	B6	0.0	Z9C	0	0	0	0
10-580	F	1930		01	1948	52	1973	3	B3	0.0	Z9C	1	0	6	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	13	0
10-595	F	1908		01	1928	104	1977	6	C6	0.0	Z9	2	0	25	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
10-596	F	1909		01	1927	6	1973	6	B3	0.0	Z9C	2	0	23	0
10-597	F	1911		01	1928	17	1976	2	B3	0.0	Z9C	1	0	8	0
10-598	F	1914	1979	01	1934	156	1973	1	B6	0.0	Z9C	0	0	3	0
10-601	M	1920		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
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	5	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	26	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	1	0
10-627	M	1911		07	1928	208	1974	4	G6	0.00420	Z5	1	1	11	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	1973	0	B6	0.0	Z9C	0	0	1	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	6	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	4	0
10-650	F	1926		01	1946	59	1973	8	B2	0.0	Z9C	2	0	18	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	5	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	24	0
10-659	F	1904		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	47	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	9	0
10-664	F	1925		01	1943	1	1973	3	B3	0.0	Z9C	1	0	8	0
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
10-670	M	1932		06	1955	780	1974	2	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
10-683	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		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	33	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	1977	1	C6	0.0	Z9C	0	0	4	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
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	2961	0
10-831	M	1879	1926	05	1925	+0	1977	786	A1	0.0	Z9	36	0	39	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	16	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	41	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	0.00131	Z8B	1	1	9	8
10-870	F	1911	1978	07	1944	550	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	8	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
10-903	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	0	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	2	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
10-916	F	1915		01	1946	2	1974	0	B6	0.0	Z9C	0	0	0	0
10-918	F	1907		01	1923	0	1976	0	B6	0.01000	Z2B	0	0	0	0
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	5	0
10-932	M	1903		76	1919	208	1979	15	B2	0.0	Z9B	5	0	54	0
10-933	F	1924		01	1943	3	1974	2	B6	0.0	Z9C	0	0	5	0
10-934	F	1924		01	1948	1196	1974	0	B6	0.0	Z9C	0	0	0	0
10-935	M	1925		07	1959	780	1974	0	B6	0.0	Z9C	0	0	0	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	11	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	5	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	72	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	6	0
10-959	F	1929		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	B3B	209	318	3275	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		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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	16	0
10-978	M	1927		07	1943	1612	1974	4	B3	0.0	Z9C	0	0	2	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	3	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	2	0
10-992	F	1919		01	1942	39	1974	0	B6	0.0	Z9C	0	0	0	0
10-993	F	1904		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	8	0
11-004	M	1924		01	1946	702	1979	1	B6	0.0	Z9	0	0	1	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
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	113	642
11-017	F	1906		01	1923	1	1977	0	G6	0.00907	Z2	0	0	0	0
11-018	F	1908		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	1976	0	B6	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	4	B3	0.0	Z9B	1	0	8	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	1918		06	1934	2184	1977	51	B2	0.0	Z9C	8	0	50	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	14	0
11-040	M	1915		67	1939	2132	1980	6	C3	0.0	Z9C	1	0	4	0
11-042	M	1923		07	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	1975	0	B6	0.01160	Z2B	0	0	0	0
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	8	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	5	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
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	4	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
11-161	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	5	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	2	0
11-196	F	1916		61	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	1976	4	B6	0.0	Z9B	1	0	11	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
11-262	F	1913		01	1933	208	1975	2	B3	0.0	Z9C	1	0	7	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
11-297	M	1914		67	1934	1872	1976	9	B2	0.0	Z9C	2	0	11	0
11-302	F	1901		01	1924	0	1976	0	B6	0.01000	Z2B	0	0	0	0
11-304	F	1912		07	1928	150	1978	0	B6	0.0	Z9B	0	0	0	0
11-329	F	1915		17	1933	156	1978	0	C6	0.0	Z9	0	0	0	0
11-361	F	1910		01	1925	23	1977	1	B6	0.00230	Z8B	0	0	5	6
11-368	F	1910		01	1927	1	1977	0	G6	0.00230	Z8	0	0	0	0
11-389	F	1908		01	1924	7	1976	3	B3	0.01150	Z2B	1	6	14	89
11-411	F	1905		17	1922	345	1979	33	B2	0.00713	Z2B	10	49	152	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	8	0
11-561	F	1910		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	8	8
11-584	F	1904		01	1922	15	1977	4	B6	0.0	Z9B	1	0	19	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
11-637	M	1902		06	1934	52	1975	0	B6	0.0	Z9B	0	0	0	0
11-652	F	1927		06	1953	208	1978	0	C6	0.0	Z9C	0	0	0	0
11-655	M	1922		06	1953	156	1976	1	B3	0.0	Z9C	0	0	2	0
11-660	F	1928		01	1947	416	1976	5	B2	0.0	Z9C	1	0	10	0
11-661	M	1926		07	1948	1456	1976	6	B2	0.0	Z9C	1	0	3	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
11-871	F	1925		01	1940	276	1977	5	B3	0.0	Z9B	1	0	14	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
11-947	F	1925		01	1947	260	1975	4	B3	0.0	Z9B	1	0	9	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	1977	0	B6	0.0	Z9B	0	0	0	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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
12-026	F	1914		01	1942	156	1976	0	B6	0.0	Z9B	0	0	0	0
12-033	F	1925		07	1950	52	1975	3	B3	0.0	Z9B	1	0	6	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	8	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
12-064	F	1924		01	1942	156	1979	0	B6	0.0	Z9B	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
12-086	F	1925		07	1942	156	1977	2	B6	0.0	Z9B	0	0	6	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	6	0
12-098	F	1930		01	1951	52	1974	1	B6	0.0	Z9C	0	0	1	0
12-099	F	1929		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
12-111	F	1929		01	1947	19	1974	4	B3	0.0	Z9C	1	0	9	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	2	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		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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	11	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	0	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	16	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	2	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
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	19	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	1921	13	1979	2	C6	0.0	Z9C	1	0	10	0
12-198	M	1909		17	1929	520	1976	0	B6	0.0	Z9B	0	0	0	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	938	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
12-236	F	1928		01	1960	130	1977	1	B6	0.0	Z9C	0	0	1	0
12-237	F	1936		01	1954	52	1977	0	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		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	9	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		11	1936	360	1980*	2	B3	0.0	Z9C	0	0	6	0
12-297	F	1923		01	1943	26	1978	0	C6	0.0	Z9C	0	0	1	0
12-299	F	1921		01	1942	104	1979	0	C6	0.0	Z9C	0	0	0	0
12-300	F	1915		11	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	16	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
12-349	F	1940		07	1961	156	1974	1	B6	0.0	Z9C	0	0	1	0
12-350	F	1906		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	18	0
12-359	F	1914		16	1940	52	1979	1	B6	0.0	Z9C	0	0	4	0
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	63	0
12-385	F	1909		01	1942	182	1979	8	C6	0.0	Z9C	2	0	23	0
12-390	F	1905		01	1929	7	1979	17	G4	0.0	Z9	5	0	72	0
12-392	F	1923		16	1942	52	1978	0	C6	0.0	Z9C	0	0	0	0
12-397	M	1916		06	1947	520	1979	15	C3	0.0	Z9B	3	0	23	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	1980	189	C2	0.0	Z9C	62	0	943	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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
12-450	M	1911		07	1946	20	1977	0	B6	0.0	Z9B	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	19	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
12-544	F	1921		01	1941	534	1975	4	B3	0.0	Z9B	1	0	10	0
12-545	F	1920		01	1937	902	1975	11	B2	0.0	Z9B	3	0	27	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	4	0
12-552	F	1922		01	1940	338	1975	7	B3	0.0	Z9B	2	0	19	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 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	2	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		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		17	1926	1820	1979	0	G6	0.0	Z9	0	0	0	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
12-635	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	2	0
12-656	M	1944		01	1962	104	1976	2	B2	0.0	Z9C	0	0	1	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
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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	1976	0	B6	0.0	Z9C	0	0	1	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	3	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
12-777	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
12-784	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	4	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
12-802	F	1906		01	1943	14	1978	2	C6	0.0	Z9C	1	0	6	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
12-831	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

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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	5	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	1976	2	B3	0.0	Z9C	0	0	4	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
12-924	F	1905		01	1950	17	1977	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		01	1942	4	1977	0	C6	0.0	Z9C	0	0	0	0
12-933	F	1923		01	1944	52	1979	2	B3	0.0	Z9C	0	0	4	0
12-941	F	1925		01	1944	2	1980*	0	B6	0.0	Z9C	0	0	0	0
12-942	F	1898		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	2	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	Z9B	0	0	0	0
12-983	F	1921		01	1940	1040	1976	6	B2	0.0	Z9C	1	0	13	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
13-002	F	1901		61	1923	468	1977	0	B6	0.0	Z9C	0	0	0	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
13-007	M	1911		67	1951	676	1976	1	B6	0.0	Z9B	0	0	1	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	1942	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	4	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		17	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	B6	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	1978	0	B6	0.0	Z9B	0	0	0	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		17	1942	1612	1978	2	B6	0.0	Z9B	0	0	3	0
13-109	F	1910		01	1943	1	1979	7	G6	0.0	Z9	2	0	20	0

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1980

(1) CASE	(2) SEX	(3) BORN	(4) DIED	(5) EXP TYPE	(6) YEAR FIRST EXP	(7) EXP DUR WKS	(8) YEAR OF MEAS	(9) RA226 NCI	(10) RA226 METHOD + ERR	(11) RA228 TO RA226 RATIO	(12) RA228 METHOD + ERR	(13) INPUT RA226 UCI	(14) INPUT RA228 UCI	(15) CUM RADS RA226	(16) CUM RADS RA228
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		07	1942	130	1978	0	B6	0.0	Z9B	0	0	0	0
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		17	1939	204	1979	1	B6	0.0	Z9B	0	0	3	0
13-151	F	1904		07	1927	936	1978	1	B6	0.0	Z9B	0	0	3	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
13-161	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
13-170	F	1923		01	1943	104	1979	0	B6	0.0	Z9C	0	0	0	0

APPENDIX B. Radium-Induced Malignancies

Measured Persons

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

There are 60 bone sarcoma cases and 30 sinus or mastoid carcinoma cases among the 2259 persons whose body burdens of radium have been measured. Five persons had both types of tumor (cases 01-179, 03-110, 03-402, 03-429, and 03-648) so that there are 85 measured persons considered to have radium-induced malignancies. There is one more case (03-459) in Table 2 than appeared in the corresponding table of the 1980 annual report.[1] A squamous-cell carcinoma of the sphenoid sinus of this former dial painter was diagnosed in 1980. Positive evidence is lacking that two of the cases (03-110 and 03-417) listed in Table 2 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 3 and 4 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 radium cases with unmeasured body burdens for whom medical data are available. We have evidence that eight of these unmeasured persons had early radioactivity measurements which were interpreted to show a positive indication of radium in the body; work is in progress to estimate lower limits of radium content for these cases.

Reference

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Table 1 Bone Sarcomas in Persons with Known Radium Body Content as of 31 December 1980.

CASE	SEX	BORN	DIED	EXPOSED	CUM.RADS	DIAGNOSED
00-003	F	1894	1927	1917	44441	1927
01-079	F	1901	1943	1920	21115	1942
01-032	F	1908	1940	1924	18248	1940
01-033	F	1908	1931	1923	18023	1930
03-584	F	1905	1959	1923	16821	1958
03-648	F	1903	1956	1922	16713	1956
00-019	F	1895	1946	1917	15042	1946
01-009	F	1898	1945	1918	14306	1944
03-213	F	1892	1955	1925	14049	1954
00-027	F	1902	1942	1918	13175	1942
01-105	F	1898	1945	1921	12555	1945
00-006	F	1903	1930	1918	11760	1930
03-671	F	1906	1953	1922	11314	1952
01-046	F	1903	1943	1920	11190	1942
00-004	F	1900	1931	1917	11063	1930
00-028	F	1902	1933	1917	10265	1930
01-172	F	1898	1968	1916	9628	1968
03-201	F	1909	1963	1922	9586	1962
01-389	F	1910	1930	1923	9507	1930
05-215	F	1886	1968	1920	9272	1960
01-562	F	1901	1931	1920	7143	1931
01-103	F	1903	1946	1922	7025	1946
00-023	F	1900	1929	1917	6928	1929
03-215	M	1896	1971	1925	6860	1957
01-031	F	1906	1934	1925	6824	1934
03-401	F	1900	1963	1923	6781	1962
01-011	F	1872	1937	1919	6678	1936
00-005	F	1901	1939	1917	6643	1939
05-953	F	1902	1978	1918	6589	1977
03-619	F	1903	1962	1922	6184	1962
01-007	F	1886	1949	1926	5972	1948
01-059	F	1905	1967	1920	5182	1962
03-118	F	1898	1955	1931	5159	1955
00-007	F	1903	1935	1919	5046	1934
03-429	F	1908	1976	1923	4387	1967
01-051	F	1904	1977	1923	4265	1972
01-024	F	1901	1956	1916	4085	1956
03-234	F	1890	1965	1915	3810	1964
05-281	F	1898	1964	1916	3804	1956
03-402	F	1905	L	1923	3761	1953

Table 1 Bone Sarcomas in Persons with Known Radium (cont.) Body Content as of 31 December 1980.

CASE	SEX	BORN	DIED	EXPOSED	CUM.RADS	DIAGNOSED
01-179	F	1890	1966	1924	3642	1943
01-239	F	1901	1958	1917	3153	1955
01-520	F	1882	1969	1930	3132	1967
01-073	F	1900	1969	1921	3048	1969
01-099	F	1905	1945	1924	2923	1942
01-026	F	1905	1958	1925	2729	1955
03-649	F	1906	1954	1924	2664	1953
01-025	F	1886	1952	1924	2497	1950
03-212	F	1902	1951	1927	2412	1951
03-210	M	1906	1958	1926	2396	1956
01-613	F	1906	1936	1923	2319	1935
03-209	M	1894	1960	1925	1698	1958
03-216	F	1907	1961	1922	1606	1959
01-268	F	1901	1968	1920	1602	1959
01-112	F	1908	1955	1924	1547	1954
03-227	F	1878	1952	1930	1470	1949
03-110	F	1899	1967	1931	1467	1963
03-455	F	1906	L	1922	1445	1934
03-106	F	1876	1959	1931	1323	1957
01-439	F	1880	1953	1922	888	1949

Table 2 Carcinomas of the Paranasal Sinuses and Mastoid Air Cells in Persons with Known Radium Body Content as of 31 December 1980.

CASE	SEX	BORN	DIED	EXPOSED	CUM.RADS	DIAGNOSED
01-145	F	1900	1957	1918	25701	1957
01-008	F	1900	1958	1917	22309	1958
01-149	F	1888	1959	1919	20067	1958
01-087	F	1905	1979	1921	18114	1957
03-648	F	1903	1956	1922	16455	1955
03-232	F	1898	1957	1917	14736	1956
01-006	F	1899	1938	1919	8505	1938
03-240	F	1916	1955	1930	7655	1953
03-206	M	1914	1975	1936	7056	1974
01-014	F	1901	1949	1916	6799	1949
03-676	F	1897	1977	1924	6433	1976
01-179	F	1890	1966	1924	6019	1965
03-429	F	1908	1976	1923	4783	1973
03-402	F	1905	L	1923	4596	1964
03-101	F	1908	1971	1931	4448	1970
01-171	M	1895	1975	1914	4311	1966
03-407	F	1905	1961	1923	4206	1959
03-214	F	1895	1966	1925	3964	1959
03-235	F	1900	1968	1928	3803	1965
03-459	F	1906	1980	1924	3537	1980
03-126	F	1910	1965	1931	3449	1965
01-573	F	1892	1945	1916	3307	1945
03-105	M	1903	1957	1931	3143	1957
03-423	F	1907	1972	1923	2036	1971
03-417a	F	1909	1966	1924	1894	1962
03-141	M	1906	1963	1933	1550	1963
01-022	F	1900	1951	1917	1544	1951
03-110	F	1899	1967	1931	1467	1963
05-284	F	1899	1973	1919	1179	1970
03-488	F	1907	1975	1922	605	1973

(a) Carcinoma of case 03-417 apparently arose in R. gingiva (posterior maxilla).

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

CASE	SEX	BORN	DIED	EXPOSED	DIAGNOSED
00-011	F	1896	1936	1917	1935
00-013	F	1899	1933	1917	1933
00-030	F	1903	1924	1918	1923
00-031	F	1903	1940	1920	1938
00-035	F	1900	1941	1917	1941
01-088	F	1906	1931	1923	1931
01-107	F	1909	1935	1923	1935
01-108	F	1908	1947	1924	1947
01-117	F	1907	1931	1922	1931
01-387	F	1895	1943	1918	1943
01-465	M	1881	1943	1925	1943
01-695	F	1908	1935	1923	1935
03-658	F	1903	1938	1922	1938
03-660	F	1907	1936	1923	1935
03-661	F	1906	1934	1922	1934
03-665	F	1909	1930	1924	1929
03-680	F	1906	1946	1924	1943
03-759	F	1904	1930	1924	1930
03-800	F	1908	1945	1924	1944
03-806	F	1896	1956	1922	1956
03-848	F	1903	1958	1922	1958
05-534	F	1897	1939	1917	1937
05-987	F	1901	1962	1918	1962
09-087	M	1891	1934	1912	1933

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

Table 4 Probable or Confirmed Malignant Tumors of the Paranasal Sinuses and Mastoid Air Cells in Exposed Persons with Unknown or Uncertain Radium Body Content.(a)

CASE	SEX	BORN	DIED	EXPOSED	DIAGNOSED
01-587	F	1894	1943	1919	1943
03-675b	F	1896	1960	1922	1959
03-760	F	1907	1946	1924	1946
03-772	F	1904	1953	1922	1953
03-785	F	1903	1955	1925	1953

(a) All 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.

PUBLICATIONS AND PRESENTATIONS BY THE STAFF OF
THE CENTER FOR HUMAN RADIOBIOLOGY
FOR THE PERIOD JULY 1980 THROUGH JUNE 1981

A. PUBLISHED PAPERS

E. E. Adams and A. M. Brues, Breast cancer in female radium dial workers first employed before 1930, J. Occup. Med. 22, 583-587 (September 1980).

A. M. Brues, The long-term follow-up of radium dial painters and thorium workers, The Medical Basis for Radiation Accident Preparedness, Proc. REAC/TS Int. Conf., Oak Ridge, Tennessee, Oct. 18-20, 1979, K. F. Hubner, M.D. and S. A. Fry, M.B., Ch.B., Eds., Elsevier/North Holland, pp. 441-450 (1980).

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A. P. Polednak, A. T. Keane and W. L. Beck, Estimation of radiation doses to the lungs of early uranium-processing plant workers, Environ. Res.

C. PAPERS SUBMITTED FOR PUBLICATION

R. E. Toohey, M. H. Bhattacharyya, R. D. Oldham, R. P. Larsen and E. S. Moretti, Distribution of gastrointestinally absorbed plutonium in the dog, Radiat. Res.

R. A. Schlenker, A. T. Keane and R. B. Holtzman, The retention of ^{226}Ra in human soft tissue and bone; implications for the ICRP20 alkaline earth model, Health Phys.

D. PAPERS PRESENTED AT MEETINGS

25th Annual Meeting, Health Physics Society, Seattle, WA, July 20-25, 1980

R. E. Toohey, Radioactivity measurements of former military personnel exposed to weapon debris.

The American Statistical Association Meeting, Houston, TX, Aug. 11-12, 1980

L. Sanathanan and H. F. Lucas, Jr., An empirical Bayes model for estimating radium intake from exposure duration.

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M. J. Harris, Morphometry of the paranasal sinuses and mastoid air cells.

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A. F. Stehney, Mortality experience among women employed in the radium-dial industry before 1930.

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R. A. Schlenker, Risk estimates for bone. To be published in proceedings.

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R. A. Schlenker and A. T. Keane, Improvement of the ICRP20 alkaline earth model.

R. E. Toohey, M. A. Essling and J. Y. Sha, Measurements of ^{202}Tl in vivo.

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