ANL-77-65
Part II

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# RADIOLOGICAL AND ENVIRONMENTAL RESEARCH DIVISION ANNUAL REPORT



## ~~Center for Human Radiobiology~~

## July 1976—June 1977

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ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

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# RADIOLOGICAL AND ENVIRONMENTAL RESEARCH DIVISION ANNUAL REPORT



~~Center for Human Radiobiology~~

July 1976 through June 1977

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

Preceding Report: ANL-76-88, Part II, July 1975–June 1976

## FOREWORD

During the past year, the Center began a study of the health status of the former employees of a plant that processed thorium ores from the mid-1930's to 1973. Under way are a mortality study, from death certificates, of about 3900 persons who were identified from company records, and a morbidity study, by questionnaire and medical records, of a subpopulation of 558 men who worked one year or more in occupations most exposed to thorium. In this Annual Report, paper 13 reports that measurable amounts of thorium daughter products were found by in vivo measurements of some men randomly selected from the group of 558 for medical and radioactivity examinations.

The reader's attention is also directed to other papers of special interest. Paper 15 reports that soluble plutonium is oxidized to the +6 state when drinking water is chlorinated, and points out that uptake of ingested plutonium, therefore, may be much higher than currently accepted in setting safety standards. Transformation of mammalian cells in culture when irradiated by alpha particles is reported in paper 5, and a mechanism for a linear component in the two-target model for induction of bone cancer by alpha particles is described in paper 20.

We with to express our gratitude to St. Mary's Hospital, Orange, New Jersey, for its assistance to the Center for many years. The Hospital generously provided office space and back-up services for our New Jersey field office until mid-1977, when its need for more space forced it to discontinue this association. In particular, we thank Sister Mary Fidelise, Administrator, and Mr. Philip G. McAndrew, Associate Administrator of St. Mary's Hospital, for their help.

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# LOCAL BONE MINERAL MASS AS A FUNCTION OF DOSE IN RADIUM CASES

Robert A. Schlenker, Billie G. Oltman, and Thomas J. Kotek

Bone mineral mass at specific sites in the forearms and fingers of females with exposure to radium and mesothorium appears to have no dependence on dose. Data analysis is continuing, so these results should be considered preliminary. Future analyses will include males.

## Introduction

Localized areas of bone loss are seen in x-ray films of radium patients who have residual body burdens above about 0.1 μCi $^{226}$Ra pure radium equivalent. To determine if loss occurs which is not visible on radiographs, and to provide a quantitative measure of the amount of bone present, bone mineral mass is measured from the attenuation of an x-ray beam (27 keV) scanned across a bone. Each measurement gives the mass in a 2 mm wide slice of bone, and measurements have been made at two to ten sites on the forearms and hands on all but a few subjects examined in the last 5 years. Altogether, 998 persons have been measured: 892 radium patients, 20 patients with other radionuclide exposures, and 86 persons with no exposure; there were 827 females and 171 males; 946 were alive when measured and 52 were dead.

## Dose-Response Relationship

In Figure 1, the dose response is plotted for each of the 278 female radium patients who had a measurement near the midshaft of the right radium and a $^{226}$Ra burden detectable by whole body counting (≥ 3 nCi). The response parameter is the deviation from the control mean value (residual) divided by the standard deviation of the control population. For this plot, the control population consists of the 533 females who had a measurement near the midshaft of the right radius and who were either unexposed or who had radium exposure but with $^{226}$Ra burdens less than detectable by whole body counting. No tendency of the response to decrease or increase with dose is seen visually or is detected statistically at a 5% significance level. Similar results are obtained

for other scanning sites in the female.

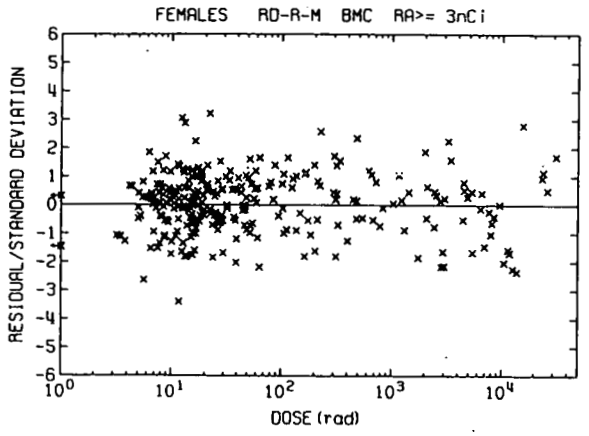


FIG. 1.--Dose-response plot for bone mineral mass at the radius midshaft in females. The ordinate is the deviation of bone mineral mass from the normal value, divided by the standard deviation in normal values. (ANL Neg. 149-77-343)

## The Localized Nature of Bone Loss

The dose-response plot suggests that radium has no effect at all on bone mass. This is at odds with the observations of osteolytic areas in radiographs. The answer appears to be that bone loss is a very localized phenomenon and the presence of a few prominent lesions does not imply the existence of many small, invisible lesions, or of abnormal thinning of the cortex. Figure 2 supports this interpretation. It compares the bone mineral mass in the radius of a patient with a 32,000 rad skeletal dose and the mass in the radius of an

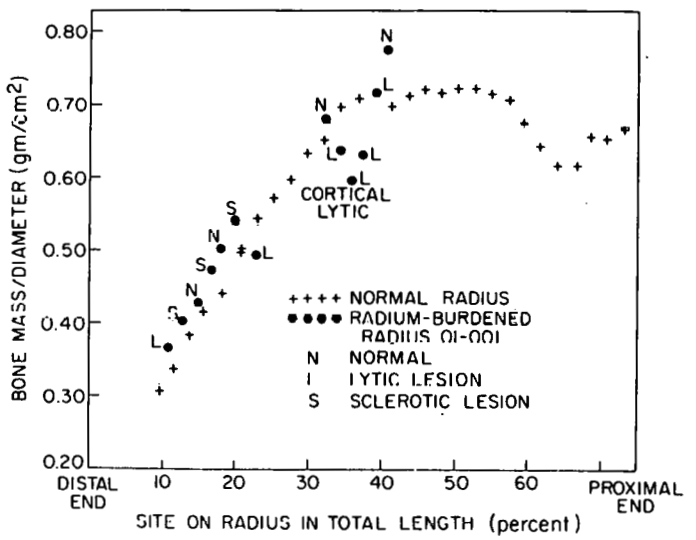


FIG. 2.--The distribution of bone mineral along the radius in a normal, compared with a radium patient with a 32,000 rad mean skeletal dose. (ANL Neg. 149-6478)

unexposed person of the same age and sex. Downward breaks in the upward trend of radium case values are seen at the positions of two visible osteolytic lesions. Otherwise, mineral mass in the two cases follows parallel trends as it does when two normals are compared.

Further Work

The analysis of these data is in progress. A more detailed search for dose dependence in females is under way. The dependence of bone width on dose and the analysis of data on males is yet to be carried out.

# MARROW, OVARY, AND BREAST DOSES DELIVERED BY CHR DIAGNOSTIC X-RAY EXAMINATIONS—AN UPDATE

Robert A. Schlenker and Billie G. Oltman

The mean absorbed dose averaged over the marrow volume in a RANDO phantom is 232 ± 14 mrad and 175 ± 26 mrad when the ANL examination is made using 1 mm Al and 3 mm Al added filtration, respectively; it is 606 ± 69 mrad when the MIT examination is made. The absorbed dose averaged over the ovaries is 243 ± 25 mrad and 162 ± 38 mrad for 1 mm Al and 3 mm Al at ANL and 606 ± 40 mrad for the MIT examination. Breast doses are 388 ± 35 mrad, 226 ± 9 mrad, and 333 ± 103 mrad. Dose reduction could be achieved by using a faster film-screen combination for the MIT examination, by routinely using 3 mm Al added filtration at ANL and by improving the collimation at ANL.

## Introduction

Last year, we reported marrow and ovary doses delivered to a RANDO phantom by the CHR skeletal x-ray examination.[1] Since then, we have recalibrated our dosimeters, remeasured the marrow and ovary doses, measured breast doses, and made dose measurements at the Cambridge field station (MIT). We report our revised and new dose values here, using the new values of the calibration factor.

## X-Ray Examinations

The projections, kVp and mAs used in the examinations of the phantom, are presented in Table 1. No exposures of the extremities were made because the phantom lacks arms and has only leg stumps. Otherwise, the projections are the same as used with patients. The kVp and mAs at ANL are also those used with patients. The kVp and mAs at MIT were set in consultation with the radiologist in order to obtain acceptable films. Examinations at ANL were made with 1 mm Al and 3 mm Al added filtration, corresponding to total filtrations equivalent to 3.5 mm Al and 5.5 mm Al, respectively. The x-ray machine, film, screens, and processing used at ANL were described last year.[1]

The MIT examinations were made with a Picker Pictronic 500 generator. It is a single phase, full wave rectified unit which has 145 kVp and 500 mA

TABLE 1. X-Ray Examinations Given to the Phantom at ANL and MIT

| | kVp | | | mAs[a] | |
|---|---|---|---|---|---|
| | ANL | | | | |
| Projection | 1 mm Al | 3 mm Al | MIT | ANL | MIT |
| Skull, AP | 80 | 80 | 83 | pt | 100 |
| Skull, lat. | 80 | 80 | 70 | pt | 100 |
| Skull, mod. Waters, PA | 80 | 80 | 78 | pt | 100 |
| Sphenoid, PA | 80 | 80 | 88 | pt | 100 |
| Law's view of mastoids, r. & l., lat. | 80 | 80 | -- | pt | -- |
| Stenvers' view of mastoids, r. & l., tang. | 80 | 80 | 78 | pt | 100 |
| Mandible, r. & l., tang. | 80 | 80 | 80 | pt | 30 |
| Cervical spine, AP | 70 | 78 | 68 | pt | 70 |
| Cervical spine, lat. | 78 | 78 | 78 | 30 | 40 |
| Chest, PA | 110 | 110 | 96 | pt | 10 |
| Chest, lat. | 110 | 110 | 116 | pt | 15 |
| Thoracic spine, AP | 76 | 82 | 80 | pt | 100 |
| Thoracic spine, lat. | 78 | 84 | 60 | pt | 500 |
| Lumbar spine, AP | 72 | 80 | 75 | pt | 90 |
| Lumbar spine, lat. | 78 | 82 | 75 | pt | 500 |
| Pelvis, AP | 72 | 80 | 80 | pt | 100 |
| Shoulder, r. & l., AP | 50 | 60 | 65 | pt | 35 |
| Femur, r. & l., AP | 58 | 62 | 60 | pt | 100 |
| Hip, r. & l., lat. | -- | -- | 80 | -- | 100 |

[a] The entry "pt" indicates that the mAs was controlled by the phototimer. The actual mAs will vary according to the placement of the phantom relative to the phototimer. When left and right projections are made, the mAs value shown is used for each one.

capacity. The tube is a Machlett Dynamax 69B with a measured focal spot size of 1.3 mm × 1.9 mm and inherent filtration specified as 0.6 mm to 1.0 mm Al equivalent at 70 kVcp. The collimator is a Machlett Collimaster M with filtration equivalent to 2.5 mm Al at 150 kVp. For this work, the total filtration was assumed to be equivalent to 3.5 mm Al at all kVp. The focus-to-film distance was 72 in for the PA chest, lateral chest and lateral cervical spine projections and 40 in for all others. A Potter-Budky grid and Du Pont Cronex or Radelin par speed screens were used with all exposures. High speed screens may be used with the lateral lumbar spine, lateral thoracic spine, or lateral chest projections with large patients. Du Pont Cronex 4 film and a Kodak X-omat Processor with 90 s development at 90°F are used.

## Calibration

Marrow, ovary, and breast dose are assumed to be muscle equivalent. The dose, measured by one dosimeter is

$$D_{muscle} = 0.869 \frac{(\mu_{en}/\rho)_{muscle}}{(\mu_{en}/\rho)_{air}} \times \frac{X}{L} \times L$$

where L is the dosimeter response. The roentgen-to-rad conversion factor, $0.869\ (\mu_{en}/\rho)_{muscle}/(\mu_{en}/\rho)_{air}$ is a tabulated quantity.[2] The number of milliroentgen per unit dose of dosimeter response, X/L, is an empirical quantity. Both quantities depend on energy. Their product, the calibration factor, is plotted in Figure 1 for the ANL machine. No measurements of X/L were made for the MIT machine. The ANL data for 1 mm Al added filtration are assumed to apply to it. The calibration factors were averaged over the set of kVp values used in each examination to produce calibration constants. Total number of exposures at a given kVp was used as the weighting factor. Thus, the constant is given by

$$\bar{c} = \frac{\Sigma N_i c_i}{\Sigma N_i}$$

where $N_i$ is the number of exposures made at the ith kVp and $c_i$ is the corresponding calibration factor. The constants and their standard deviations are presented in Table 2.

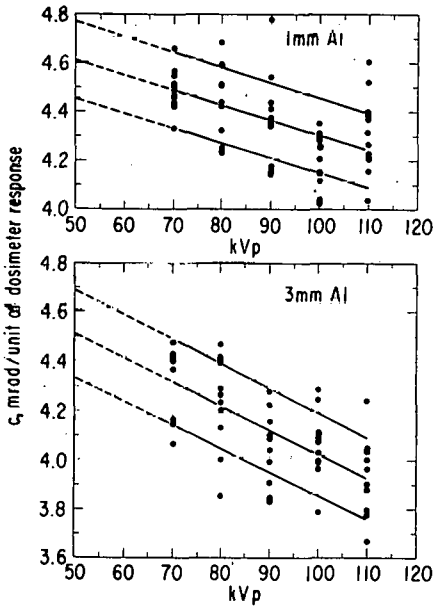


FIG. 1.--Calibration factors for the ANL machine with 1 mm Al and 3 mm Al added filtration. The central line is least squares fit to the data points, shown as dots. The lines above and below lie one standard deviation away. The dashed portions are extrapolations from 70 kVp to 50 kVp. (ANL Neg. 149-77-345)

TABLE 2. Calibration Constants in mrad Per Unit of Dosimeter Response

| Machine and filtration | $\bar{c}$ and Standard deviation |
|---|---|
| ANL, 1 mm | 3.91 ± 0.15 |
| ANL, 3 mm | 3.75 ± 0.17 |
| MIT | 3.94 ± 0.15 |

Marrow dose is enhanced by photoelectrons which are generated in bone and stop in marrow. The enhancement factor is dependent on marrow cavity dimension and on x-ray energy.[3] The effective beam energies for the various projections have an average of about 32 keV and mean cavity dimensions in cancellous bone range between 580 and 900 μm, depending on the site.[4] An enhancement factor of about 1.07 looks appropriate for this energy and range of cavity dimensions.* Thus, the light output from each dosimeter can be translated into tissue dose using the equations

$$D_{marrow} = 1.07\ \bar{c}L$$
$$D_{ovary\ or\ breast} = \bar{c}L\ .$$

Marrow Dose

The marrow dose was measured at 90 skeletal sites which contain active marrow in the adult. Information on the marrow distribution was obtained from Ellis' paper.[5] He gives red marrow weights in 45 bones and bone groups.† The individual dose readings in a bone or group were averaged and multiplied by the marrow weight to obtain an integral dose value. These were then summed to obtain integral doses for coarser subdivisions of the skeleton or for the skeleton as a whole. Average absorbed doses were computed by dividing the integral dose in a subdivision by the total weight of active marrow which it contains. To simplify data presentation, three major subdivisions were

*Based on Table X and Figure B, Ref. 4.

†Ellis' weights total to 1045.7 g. For our computations, we adjusted each weight downward by 1000/1045.7, so that they would sum to 1000 g.

defined: (1) the head and cervical vertebrae; (2) the upper limb girdle, sternum, ribs, and thoracic vertebrae; (3) the lumbar vertebrae, sacrum, and lower limb girdle. These are called the cranial, center, and caudal regions in the tables which follow.

Integral doses, based on three replications of the examination are presented in Table 3. Values for the ANL machine with 1 mm Al added filtration exceed those when 3 mm Al added filtration is used. Values for the MIT machine are about 3 times those for the ANL machine, using either filtration. The mean absorbed dose values are presented in Table 4. The relations between dose for various examinations are the same: MIT > ANL, 1 mm > ANL, 3 mm.

TABLE 3. Integral Absorbed Dose to Active Marrow in Units of Gram Rad[1]

| | ANL machine | | |
|---|---|---|---|
| Region | 1 mm Al | 3 mm Al | MIT machine |
| Cranial | 49 ± 2 | 37 ± 3 | 117 ± 11 |
| Center | 56 ± 7 | 45 ± 4 | 212 ± 22 |
| Caudal | 127 ± 33 | 92 ± 28 | 278 ± 37 |
| Total marrow | 232 ± 14 | 175 ± 26 | 606 ± 69 |

[1] The means and standard deviations, based on 3 repeat examinations, are given. The skeleton is assumed to contain 1000g active marrow. The values have been rounded to the nearest integer. Thus, totals may appear to be in error by one unit.

TABLE 4. Mean Absorbed Dose to Active Marrow in Units of mrad

| | ANL machine | | |
|---|---|---|---|
| Region | 1 mm Al | 3 mm Al | MIT |
| Cranial | 300 ± 12 | 227 ± 15 | 709 ± 64 |
| Center | 173 ± 21 | 137 ± 11 | 650 ± 69 |
| Caudal | 249 ± 45 | 181 ± 54 | 545 ± 73 |
| Total marrow | 232 ± 14 | 175 ± 26 | 606 ± 69 |

The doses delivered by the lateral lumbar spine projection alone were measured at MIT and are presented in Table 5. A single exposure was made, so the values may not be good estimates of the means for several repetitions. Nevertheless, by comparing them with the MIT data in Tables 3 and 4, a sense of the importance of this projection can be gained. It contributes approximately 50% of the dose to the caudal region, about 20% of the dose to the center region, and about 30% of the dose to the total marrow. For comparison, 22 films were made during an examination at MIT; so on the average, 1/22, or about 5%, of the dose was delivered per film. Thus, dose from the lateral lumbar spine projection greatly exceeds the average.

Large standard deviations are found for some of the entries in Tables 3 and 4, reflecting large variations in the underlying data. The calibration constant has a coefficient of variation of 4%. The average dose in any region is based on the average of many dosimeter readings and, thus, has a much smaller calibration error. It is clear that the variation in doses is not due to calibration. Nor is it due to chance variation in the radiation output from the x-ray machines. It appears to arise from differences, between examinations, in the positioning of the phantom with respect to the useful beam. This causes different portions of the skeleton to be exposed when a given projection is used in different examinations. Since the marrow content differs in different

TABLE 5. Integral Dose and Dose to Marrow for Lateral Lumbar Spine Projection at MIT[a]

| Region | Integral dose, g rad | Dose, mrad |
|---|---|---|
| Cranial | 1 | 6 |
| Center | 39 | 121 |
| Caudal | 131 | 258 |
| Total | 172 | 172 |

[a] Based on one exposure. One thousand grams active marrow assumed and values rounded to nearest integer as in Table 3.

areas, the dose will differ also. With the ANL machine, there is an additional effect. All but one of the projections are under phototimer control. The phototimer adjusts the exposure duration to maintain the same darkness near film center no matter what the thickness of the patient is. Thus, thick parts cause longer exposures than thin parts. Because the sensing element of the phototimer is quite small, a small shift in the phantom can cause a large shift in exposure duration, and this will cause a shift in the absorbed dose. The scatter in the data is, thus, a measure of the technician's ability to reproduce exactly the placement of the phantom relative to the x-ray beam or phototimer. It underscores the fact that if two patients, with identical dimensions are examined, they are unlikely to receive identical doses.

The MIT examination delivers about 3 times as much marrow dose as the ANL examination, using either filtration. This difference appears to be due to the use of different film-screen combinations. Tests, using a step wedge, indicate that the ANL detection system is several times faster than the MIT system. Also, films of the head (skull, sinuses, mastoids, mandibles) and neck (cervical vertebrae), made at MIT and at ANL, have about the same darkness while films of other areas are generally lighter for the MIT examinations. It appears, then, that if films of equal darkness had been obtained at both institutions, the ratio of MIT to ANL doses would have been even greater than reported here.

Ovary and Breast Dose

The phantom contains no ovaries, so measurements were made in two volumes approximately $3 \times 3 \times 5$ $cm^3$ centered near the medial walls of the superior halves of the innominates. The dosimeter readings in each region were averaged to obtain representative dose values. Table 6 presents values for 3 replicates of the examination, using the ANL machine with 1 mm Al added filtration. The right ovary consistently received the higher dose because it was nearer the tube focus for lateral projections. However, the right-left differences were quite variable, being 24% to 57% of the means for the data in Table 6. The differences in the MIT examinations were less, being 10% to

17% of the means.

Table 7 gives doses averaged over both ovaries for the ANL and MIT machines. The examination was repeated 3 times for each machine and filtration. The ANL machine delivers a higher dose, on the average, when 1 mm added filtration is used, than when 3 mm are used. The dose to the ovaries delivered by the MIT machine exceeds the doses from the ANL machine.

The dose from scattered radiation was determined for the ANL examination made with 1 mm Al added filtration. Projections which include the ovaries in the useful beam were deleted (AP pelvis, AP and lat. lumbar spine). No repeat examinations were made. The dose, averaged over both ovaries, was 32 mrad or about 13% of the value for the complete examination.

TABLE 6. Average Dose Values for the Ovaries Using the ANL Machine with 1 mm Al Added Filtration [a]

| | Dose, mrad | | | |
|---|---|---|---|---|
| | A | B | C | Average ± SD |
| Right | 345 | 245 | 300 | 297 ± 50 |
| Left | 192 | 192 | 184 | 189 ± 4 |
| Average | 268 | 219 | 242 | 243 ± 25 |

[a] Data from 3 replicates of the examination are presented. Numbers have been rounded to the nearest integer so averages may appear to be in error by one unit.

TABLE 7. Ovary and Breast Doses in mrad [a]

| | ANL | | |
|---|---|---|---|
| Organ | 1 mm Al | 3 mm Al | MIT |
| Ovaries | 243 ± 25 | 162 ± 38 | 606 ± 40 |
| Breasts | 388 ± 35 | 226 ± 9 | 333 ± 103 |

[a] Means and standard deviations based on 3 replicates of the examination are presented.

The dose from the lateral lumbar spine projection was determined for the MIT examination. A single exposure was made, which gave a dose of 126 mrad averaged over both ovaries. This is about 21% of the dose from all exposures. The difference between right and left ovaries was quite large, being 79% of the average.

Each breast consists of 3 sections. The dosimeter readings in a section were averaged and multiplied by the section mass to obtain an integral dose value. These were summed for each breast and divided by the total breast mass to obtain the average dose. Table 8 presents values for 3 replicates of the complete examination, using the ANL machine with 1 mm Al added filtration. The right breast consistently received the higher dose because it was nearer the tube focus for lateral projections. The difference between the right and left breast was quite variable, however. When expressed as a percentage of the average dose for the two breasts, values as low as 27% and as high as 53% are found in Table 8. When the examinations made with the MIT machine and with the ANL machine, using 3 mm Al added filtration are taken into account, the percentages range from 25% ro 79%.

Table 7 gives the doses averaged over both breasts for examinations with the ANL and MIT machines. Three complete examinations were made in each case. The ANL machine delivers a higher dose with 1 mm added filtration than with 3 mm. The dose for the MIT machine is intermediate in value. Since marrow and ovary doses with the MIT machine are higher than with the ANL machine, using either filtration, one would expect the breast doses to be higher also. The reason that they are not appears to be differences in collimation used at the two institutions. The fractions of the breast exposed by the examinations at ANL and MIT are compared in Table 9. One can see that the shoulder and thoracic spine projections at MIT tend to "save" breast radiation exposure when compared to the same projections at ANL.

## Recommendation

Our results suggest three changes which would reduce dose to the patient from the ANL and MIT diagnostic x-ray examinations:

TABLE 8. Average Dose Values for the Breasts Using the ANL Machine with 1 mm Al Added Filtration [a]

| | Dose, mrad | | | |
|---|---|---|---|---|
| | A | B | C | Average ± SD |
| Right | 456 | 435 | 484 | 458 ± 25 |
| Left | 265 | 316 | 370 | 317 ± 52 |
| Average | 361 | 376 | 427 | 388 ± 35 |

[a] Data from 3 replicates of the examination are presented. Numbers rounded as in Table 6.

TABLE 9. Breast Exposure at ANL and MIT

| | Fraction of breast within field | |
|---|---|---|
| Projection [a] | ANL | MIT |
| Chest, PA | All, both breasts | All, both breasts |
| Chest, lat. | All, both breasts | All, both breasts |
| Shoulder, r., AP | All, right breast | 1/3 to 1/2, right breast |
| Shoulder, l., AP | All, left breast | 1/3 to 1/2, left breast |
| Thoracic spine, AP | 1/2, both breasts | None |
| Thoracic spine, lat. | 1/2 to all, both breasts | None |

[a] These are the only projections in which breasts are included within the useful beam.

(1) Faster films and screens could be used with the MIT examination.

(2) The ANL examination could be made with 3 mm Al instead of 1 mm Al added filtration.

(3) The field dimensions at ANL on exposures of the breast could be reduced. Since field sizes are generally greater at ANL than at MIT, other field size reductions could also be made.

We recommend that the radiologists make these changes, if acceptable films can be obtained using the new methods.

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# BULK ETCH RATE OF LR-115 CELLULOSE NITRATE FILM

Michael J. Harris and Robert A. Schlenker

Bulk etch rate ($V_b$) of Kodak LR-115 cellulose nitrate film has been studied, and values for the parameter are presented. An interesting variability of $V_b$ has been found which has implications for microdosimetry using this type of integrating nuclear track detector. Short-term and longer-term thickness changes have been observed which may increase the uncertainty in estimations of dose using this type of detector.

## Introduction

Properties of Kodak LR-115 cellulose nitrate (CN) film have been studied extensively since the film was introduced about 10 years ago.[1-5] We have observed unusual thickness changes in several lots of LR-115 type 2 CN film following short etching treatments with NaOH. In addition, a longer term swelling phenomenon is noticeable when thickness is monitored for a week or longer post-etch. Both observations, especially the short-term effect at etch times less than 15 min influence bulk etch rate ($V_b$), a parameter useful in the calculation of absorbed dose from nuclear particles. This paper is a report of our results with a discussion and an interpretation of them.

## Materials and Methods

Sheets were selected at random from four lots of Kodak LR-115 type 2 CN film and cut into conveniently sized pieces. The pieces were placed in groups of three or more and measured for thickness, to the nearest 25 μm, on a Starrett indicator gauge calibrated against copper foils of known thickness. These pre-etch measurements of the film served as an internal control for this experiment.

The films were etched for varying times between 5 and 75 min in 2.50 ± 0.03 N NaOH standardized volumetric solution in a temperature-regulated etch bath at 60 ± 0.1°C. The etch bath was not stirred, and the films were floated sensitive side toward the surface. After etching, the films were washed twice in distilled water, dried and measured for thickness within a few minutes

for the day 0 measurement. Measurements were taken subsequently on selected days after the treatment.

Thickness of the sensitive layer was derived from the difference between pre-etch thickness and the thickness of the clear backing material measured by the method described above after all of the red dyed CN had been etched away (Table 1). $V_b$ is defined as a pre-etch film thickness minus post-etch film thickness divided by etch time.

Analysis of variance methods are being used to test equality of mean bulk etch rate at various etch times among the four lots of film. The 1% significance level was chosen as a criterion.

## Results

Figure 1 shows typical changes in film thickness as a function of etch time. The large scatter in the values is due to the different thicknesses of each lot of film. At short etch times immediately post-etch (Figure 1a), the trend of the data indicates no thickness change. After a 15 min etch time, decrease in film thickness is evident, continuing throughout all etch times studied.

TABLE 1. Sensitive layer thickness — LR-115 Type 2 CN Film

| | A<br>Lot IV.72 | B<br>Lot XII.73.IV.8 | C<br>Lot VI.74.2.1 | D<br>Lot XII.73.II.5 |
|---|---|---|---|---|
| Total thickness | 108.51 ± 0.10 μm (62) | 114.34 ± 0.05 μm (28) | 110.83 ± 0.12 μm (68) | 112.71 ± 0.12 μm (80) |
| Backing thickness | 99.03 ± 0.14 μm (10) | 100.04 ± 0.21 μm (12) | 99.15 ± 0.14 μm (10) | 100.69 ± 0.17 μm (14) |
| Sensitive layer thickness | 9.48 μm | 14.30 μm | 11.68 μm | 12.02 μm |
| Supplier's stated thickness | 10 μm | 13 μm | 10 μm | 12 μm |

*Numbers in parentheses are number of pieces of film measured.

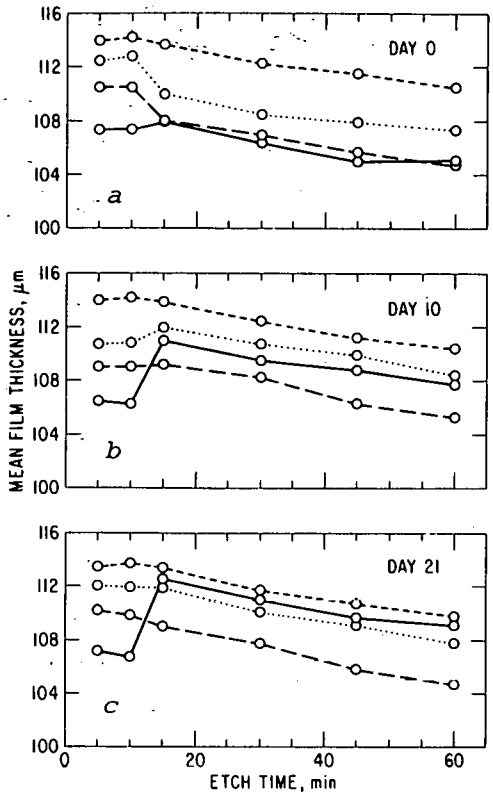


FIG. 1.--Film thickness as a function of etch time for several lots of LR-115, Type 2 CN film. Measurements for the day of etching and 10 and 21 days later are plotted. Lot A ———; Lot B — — — —; Lot C ------; Lot D .....

Figure 1b indicates a swelling of the film at shorter etch times, a behavior which is different from that observed for films measured immediately after etching on day 0. This swelling is most pronounced in Lots A and D. There is no similar change noted at longer etch times for any lot. The change in thickness noted begins 7 days post-etch and increases to day 21 (Figure 1c). Other data not presented confirm the observation.

The clear contrast between $V_b$ at short and at long etch times is shown in Figure 2. Variation in $V_b$ is greatest at the short etch times and decreases as etch time increases. At longer etch times, the slope of the line connecting data points approaches zero.

Figures 2b and 2c clearly show the tendency of Lots A, C, and D to have positive $V_b$ at etch times between 10 and 30 min, while values for lot B remain uniformly negative.

## Discussion and Conclusions

The scatter of the data values at a 5 min etch time in Figure 2a is outside the range of chance variation. It is not simply a reflection of measurement

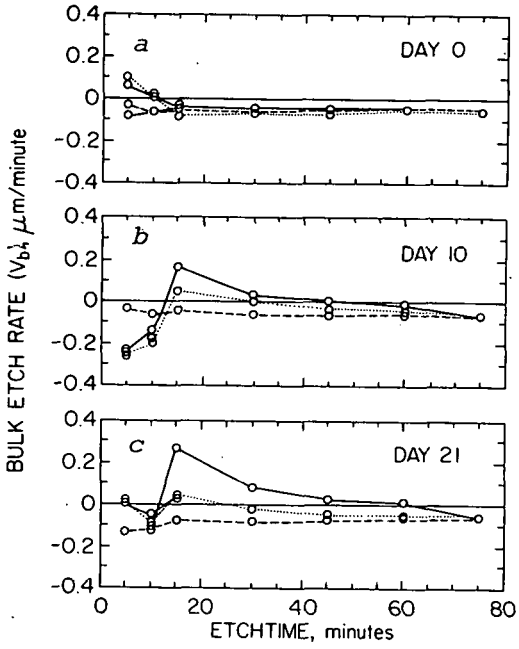


FIG. 2.--Bulk etch rate ($V_b$) as a function of etch time. a) shows the day 0 curve and illustrates the short etch time effect; b) and c) illustrate the longer term swelling effect. Lot A ———; Lot B — — — —; Lot C -------; Lot D .....

error although the coefficient of variation is much larger for the 5 min etch time (about 70%) compared with that at 60 min etch time (13%). The test for equality of means at both 5 and 10 min etch time shows them to be not equal.

Other statistical comparisons are suggested by close inspection of Figure 2a. $V_b$ for lots A and B at 5 min etch time does not differ significantly at the 1% level. The same is true of lots C and D. When these pairs are grouped, A/B has a $V_b$ of -0.050 μm/min and C/D +0.071 μm/min. The difference between pairs is significant at the 1% level, and it appears that there are two types of film which have decidedly different properties at short etch times. It should also be noted that $V_b$ for C/D is significantly different from zero at the chosen significance level, indicating that film swelling has occurred. $V_b$ for A/B is not significantly different from zero at the 1% level, and the negative value of this parameter indicates that film removal is occurring. Use of a larger sample size could clarify the questions raised by these observations.

Comparison among $V_b$ for all etch times in lots A and B leads to acceptance of the hypothesis that values of this parameter belong to a single population. The same hypothesis is rejected for lots C and D; thus, $V_b$ for these lots is dependent upon etch time. This agrees with the observation of film swelling at 5 min etch time. The $V_b$ of lots A and B, however, appears to be

independent of etch time. If one restricts intercomparison of $V_b$ to between 30 and 75 min etch time, the parameter appears to be independent of etch time for all lots. Therefore, $V_b$ in this interval of etch times may be characterized by a single value, $-0.061 \pm 0.012$ μm/min, with a standard error of 0.0015, based on a set of 64 values.

Our values of $V_b$ are in good agreement with those reported by Tanti-Wipawin,[2] but disagree by a factor of 4 from those of Qaqish and Besant[5] determined under similar etching conditions.

Some observations of the $V_b$ parameter by other investigators suggest possible explanations for the short-term swelling phenomenon we have observed. Enge and co-workers[6] and Luck[7] noted a reduction in $V_b$ related to pre-etch treatment with hot water or with etchant. It is possible that the variability we have observed in $V_b$ at short etch times in this experiment is a similar phenomenon, perhaps an activating step making possible further chemical attack on the CN.

Marchetti and co-workers[1] examined thermal characteristics of LR-115 CN film and demonstrated a decrease in $V_b$ at temperatures above 50°C, which is near the glass transition temperature for CN. It was suggested that crystallization of the molecule in the transition temperature region affected $V_b$.

Benton[8] offers another possible explanation for the short-term swelling reported here. Etching may release bound materials, such as the plasticizers used in CN film manufacture which, in turn, may produce swelling by the relaxation of secondary valence forces and flexation of the polymer chains. It is known that etching with caustic hydrolyzes the CN molecule, making this a reasonable explanation.

Interpretation of the longer-term thickness changes observed is problematic. In unpublished studies[9] into the effects of environmental factors, such as temperature, humidity, and barometric pressure on LR-115 CN film, no detectable influences were noted.

It may be concluded that $V_b$ for the lots of film examined departs significantly at short etch times from the value characteristic for the film. There are etch-process related short-term and problematic longer-term thickness

changes in LR-115, Type 2 CN film. It is suggested that this film be stored under controlled conditions and that thickness measurements be taken immediately after etching when one is studying $V_b$. The changes in $V_b$ reported indicate that careful attention should be given to their possible influence in quantitative dosimetry and in energy-range determinations.

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# EVALUATION OF LR-115 CELLULOSE NITRATE FILM FOR USE IN BONE AUTORADIOGRAPHY

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An evaluation of Kodak LR-115 cellulose nitrate (CN) film for alpha autoradiography of radium-burdened bone was undertaken. Comparison of the registration efficiency between a plaster of Paris radiator and bone samples on NTA nuclear track emulsion and on the CN film is presented. CN film was observed to record as etched-through holes 11% and as tracks only 32% of the events detected by NTA emulsion. Potential advantages and disadvantages of using CN film in microdosimetry and for adapting it to automated analysis are discussed.

## Introduction

The determination of dose from ionizing radiations requires a sensitive detector which records events quantitatively. LR-115 CN film from Eastman Kodak was evaluated because it is sensitive to alpha particles[1-4] and insensitive to beta and gamma radiation and because it may be suitable for automatic data collection, using the microanalyzer.[5] A few reports in the literature are concerned with applications of dielectric track detectors for dosimetry in hard tissues but none address practical microdosimetry problems.[1,6-9]

This report presents data which will allow the estimation of dose in radium-labeled osteons. Comparisons are made of alpha particle registration efficiency from a plaster of Paris radiator (thick source) of known activity and from cortical bone sections, and data are given on the threshold of LR-115 Type 2 CN film to particles from a thin source.

## Experimental Methods and Materials

LR-115 is a dielectric track detector consisting of a thin layer (6 μm for type 1, 10 to 13 μm for type 2) of red dyed CN on a transparent polyester backing. When exposed to alpha particles and etched in NaOH, tracks appear. Some are sufficiently long to intercept the backing and appear as holes which may be viewed in transmitted light. Each hole stands out as a bright point of light against a red background. It should be possible to detect this light with

a scanning microdensitometer such as the microanaylzer.[5]

Contact autoradiographs were made using alpha emitting sources of known activity ($^{226}$Ra - plaster of Paris radiators; $R_1$ contains 4.60 μCi, $R_2$ contains 3.83 μCi; $^{241}$Am - #165 is a thin source containing 0.0962 μCi) and cortical bone sections from CHR case 01-562. The alpha emitting sources were exposed on both LR-115, type 1 and type 2 CN film. The bone sections were exposed on LR-115, type 1 only. All sources were exposed on NTA nuclear track emulsion which served as a control for these experiments.

LR-115 films were processed after exposure in the following manner:

Type 1 – 16 min etch time at 60°C in 6.25 N NaOH, rinsed twice in distilled water;

Type 2 – 75 min etch time at 60°C in 2.5 N NaOH, rinsed twice in distilled water;

NTA – 5-min development in Kodak D-19 at 68°F,
10-min fix in Kodak Fixer at 68°F,
25-min wash in running tap water at 68°F.

Exposure time was controlled to ± 1 s, temperature to ± 0.1°C or to ± 0.5°F and solution concentration of NaOH to ± 0.05 N. Recorded tracks were counted manually, using a Zeiss microscope at 390.6× or a Leitz microscope at 480× magnification.

In determining efficiency of hole production by a thin source, LR-115 type 2 film was exposed to $^{241}$Am alpha particles made normally incident with a brass collimator and a 2.2 cm column of air. This geometry is recommended by the manufacturer for determining film sensitivity.

## Results

Figure 1 shows autoradiographs of the plaster of Paris radiator and of a typical hotspot from case 01-562. Tracks occur at a variety of angles, a characteristic of radiation from thick sources in 2π geometry. The mean diameter and standard error of 25 well-defined, randomly selected etched-through holes from the radiation is 5.7 ± 0.24 μm.

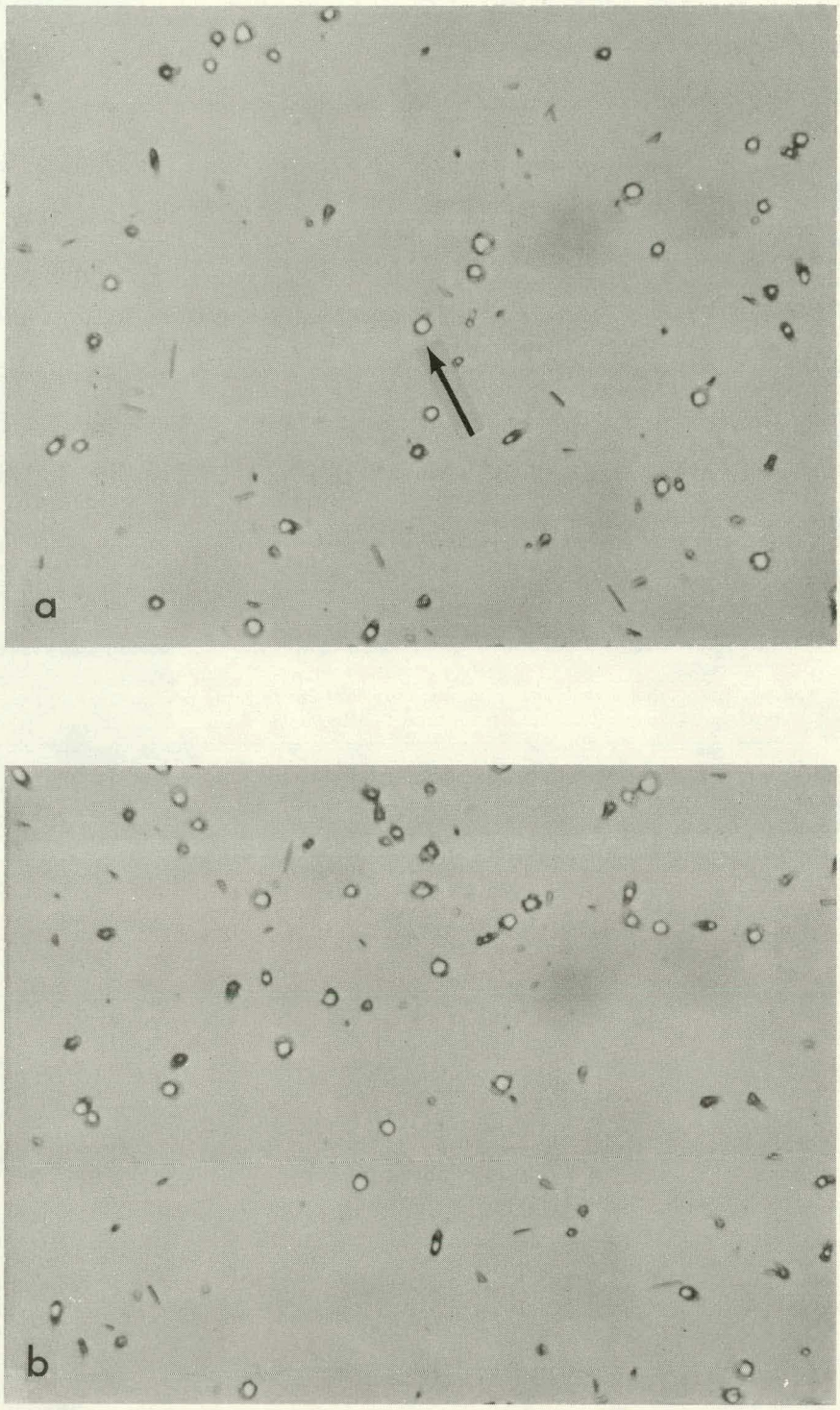


FIG. 1.--Autoradiographs from a) a plaster of Paris radiator, and b) a hotspot from case 01-562, showing etch pits and etched-through holes (arrow). × 480.

Table 1 presents track data on 18 hotspots from case 01-562, giving comparison percentages between NTA and CN detectors, as well as a comparison of etched-through holes to recorded events counted in each hotspot.

The efficiency of LR-115, types 1 and 2, to a plaster of Paris radiator is compared in Table 2, and efficiency of hole production for two irradiation geometries is shown in Table 3.

The data in the latter table for $2\pi$ geometry refer to the plaster of Paris radiator data of Table 2. The data for normally incident alpha particles in Table 3 is from the experiment using a collimated thin source. The ratio of hole production in LR-115 to track production in NTA for the collimated thin source is 6 to 9 times larger than for the thick source.

Table 1. Comparison of Alpha Tracks and Holes in Autoradiographs of Bone Sections from Left Femur Diaphysis of CHR Case 01-562 between NTA Emulsion and LR-115, Type 1 CN Film

| Osteon No. | NTA No. tracks | LR-115 No. tracks & holes | LR-115 No. holes | LR-115 hole / NTA track (× 100) | LR-115 tracks & holes / NTA track (× 100) | LR-115 hole / LR-115 tracks & holes (× 100) |
|---|---|---|---|---|---|---|
| 1E1 | 834 | 259 | 125 | 14.99 | 31.06 | 48.26 |
| 1E2 | 538 | 141 | 68 | 12.64 | 26.21 | 48.23 |
| 1E3 | 1044 | 359 | 158 | 15.13 | 34.39 | 44.01 |
| 2E2 | 325 | 113 | 29 | 8.92 | 34.77 | 25.66 |
| 2E3 | 749 | 253 | 87 | 11.62 | 33.78 | 34.39 |
| 2E4 | 387 | 133 | 47 | 12.14 | 34.37 | 35.34 |
| 3E1 | 1020 | 283 | 123 | 12.06 | 27.75 | 43.46 |
| 3E3 | 205 | 52 | 18 | 8.78 | 25.37 | 34.62 |
| 3E16 | 350 | 111 | 38 | 10.86 | 31.71 | 34.23 |
| 4E1 | 869 | 306 | 139 | 16.00 | 35.21 | 45.42 |
| 4E2 | 1004 | 318 | 129 | 12.85 | 31.67 | 40.57 |
| 4E4 | 333 | 109 | 40 | 12.01 | 32.73 | 36.70 |
| 5E1 | 889 | 245 | 83 | 9.34 | 27.56 | 33.00 |
| 5E2 | 330 | 98 | 28 | 8.48 | 29.70 | 28.57 |
| 5E5 | 58 | 25 | 7 | 12.07 | 43.10 | 28.00 |
| 8-6 | 238 | 95 | 27 | 11.34 | 39.42 | 28.48 |
| 8-11 | 288 | 73 | 20 | 6.94 | 25.35 | 27.40 |
| 8-12 | 408 | 163 | 36 | 8.82 | 39.95 | 22.09 |
| | | | | 11.39 ± 0.61 | 32.48 ± 1.24 | 35.52 ± 1.94 |

Table 2. Efficiency of Detectors to the Alpha Particles from $^{226}Ra$ and Daughters in a Thick Plaster of Paris Radiator

| Track recorder | Expected track density: Events $\mu m^{-2}$ $min^{-1} \times 10^{-4}$ | | Observed track density: Events $\mu m^{-2}$ $min^{-1} \times 10^{-4}$ | | | Observed[1]/expected (× 100) | |
|---|---|---|---|---|---|---|---|
| NTA | $R_1$ | $R_2$ | $R_1$ | | $R_2$ | $R_1$ | $R_2$ |
| | 7.64 | 6.36 | 5.71 | Tracks | 5.07 | 74.80 | 79.72 |
| LR-115, type 1 | 7.64 | 6.36 | 2.11 | Tracks & holes | 1.88 | 27.63 | 29.61 |
| | 7.64 | 6.36 | 0.47 | Holes | 0.48 | 6.17 | 7.51 |
| LR-115, type 2 | 7.64 | 6.36 | 3.03 | Tracks & holes | 3.01 | 39.70 | 47.35 |
| | 7.64 | 6.36 | 0.77 | Holes | 0.59 | 10.04 | 9.33 |

Table 3. Efficiency of Hole Production for LR-115 Films in Two Geometries

| Detector | Geometry | Alpha particle energy, MeV | No. holes/ NTA tracks |
|---|---|---|---|
| LR-115, type 1 | $2\pi$, thick source | 0–7.7 | 0.088 |
| LR-115, type 2 | $2\pi$, thick source | 0–7.7 | 0.126 |
| LR-115, type 2 | Normally incident particles, thin source | 3.4 | 0.778 |

Discussion

Tables 1 and 2 show that LR-115 registers holes and tracks less efficiently than NTA. Thus, longer exposure times are required with LR-115. The hole or track production rate in contact autoradiographs of transverse cortical bone sections can be easily estimated by assuming that the amount of radioactivity is the same in the diffuse and hotspot components. Without going into the details of the derivation, LR-115 hole and NTA track production rates in the diffuse component of the reference female skeleton are:

| | | | |
|---|---|---|---|
| LR-115, Type 1 | – | $44 \times Q \times (D/U)$ | holes/osteon/year, |
| LR-115, Type 2 | – | $63 \times Q \times (D/U)$ | holes/osteon/year, |
| NTA | – | $440 \times Q \times (D/U)$ | tracks/osteon/year, |

where Q is the skeletal content in μCi and D/U is the ratio of diffuse to uniform concentrations. In one year, then, an osteon in a female with Q = 0.5 μCi and D/U = 0.5 will produce 11 holes in LR-115, type 1, 16 holes in type 2, and 110 tracks in NTA. Tests are yet to be made with the microanalyzer, so it is not known whether 10 to 20 holes per osteon is adequate for accurate determination of diffuse levels. If so, this value would probably be at the lower end of the range.

It should be emphasized that LR-115, type 2 film, which has a thickness of ≥ 10 μm, has a noticeably greater efficiency than type 1 and would be the detector to use in any application of LR-115 film.

For α particle to produce a hole in LR-115, it must pass completely through the CN layer. If the particle enters the film with too low an energy or at too shallow an angle, it will stop before reaching the polyester backing. Also, a latent track forms only when the energy of the incident particle is below about 4 MeV. Thus, particles with somewhat higher energies can pass through the film without being detected. The production of holes is influenced by irradiation geometry and by particle energy. It is clear from Table 3 that hole production in LR-115 relative to track production in the nuclear emulsion is strongly influenced by irradiation geometry and by particle energy; this helps to explain the poorer performance of LR-115 for track registration when compared with NTA.

Since LR-115 is insensitive to beta irradiation, it has a distinct advantage over Kodak Type A autoradiographic emulsion, which has been used for rapid analysis of autoradiographs, based on optical density measurements, with the microanalyzer. The beta sensitivity of Type A, when used for contact autoradiography of 100 μm bone sections, causes hotspots to contribute to the adjacent diffuse areas. With LR-115 CN film, no such leakage would occur, and exposure times are comparable to those with Type A.

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# TRANSFORMATION OF MOUSE EMBRYO (C3H 10T1/2) CELLS BY ALPHA PARTICLES

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Mammalian cells in culture (C3H mouse 10T1/2 cells) have been shown here for the first time to be transformed by alpha irradiation when cells were irradiated with 5.6 MeV alpha particles from a Tandem Van de Graaff machine. Malignant tumors were induced following inoculation of the transformed cells into syngeneic hosts. Unirradiated control cells injected at the same concentration have, so far, failed to produce tumors. The morphology of the transformed foci was remarkably similar to that obtained by x rays and chemicals but different from virally transformed cells. When the cells were seeded at low density in the exponential growth phase, the transformation frequency per surviving cell increased approximately as the cube of the dose and peaked at an alpha particle fluence between 1.5 and 2.5 $\times$ $10^7$ alpha particles per $cm^2$ (205–342 rads). The frequency of the transformation was found to be greatly dependent on the number of cells per dish irradiated. Irradiation of larger numbers resulted in much lower frequencies of transformation. The maximum transformation frequency observed in nine separate experiments was 4% of the surviving cells. At doses greater than 200 rads the transformation frequency per surviving cell remained constant.

The present results permit us to conclude that alpha irradiation may, indeed, be able to exert a direct effect on the genome of the cell to produce malignancy without any external immunological or hormonal influences.

## Introduction

The production of bone tumors by internal alpha emitters, such as $^{226}Ra$ and $^{239}Pu$ has been well documented in many different species. These tumors characteristically arise from cells at bone surfaces. If one were to understand more fully the importance of different parameters in tumor induction, not only could one predict more accurately the likelihood of their occurrence (an important issue in protection), but, hopefully in the future, their prevention could be attempted on a more logical basis.

The study of the mechanisms of action of different carcinogens, using cells in culture, without the complexity of the in vivo system, has had a revolutionary effect on time, effort, and money required to obtain basic

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information about many of the important steps in carcinogenesis. The extent to which the basic mechanism of carcinogenesis is common to all carcinogens has been the topic of much discussion in recent years. The use of a parallel beam of alpha radiation, such as that produced by the Tandem Van de Graaff at ANL, as a probe to study such mechanisms, has many advantages over other techniques: (1) Alpha particles, unlike x rays or neutrons, provide a collimated beam of ionizing particles which are well defined in geometry and energy; (2) the range of the insult of $\alpha$ particles can be altered by merely adjusting the energy of the beam to irradiate different parts of individual cells; (3) no variables in metabolism of the different carcinogens by the cells are involved. This is a very severe limitation for studying basic mechanisms using different chemical agents.

In the present experiment, designed specifically to simulate the effect of alpha radiation on cells at bone surfaces, a parallel beam of alpha particles from a Tandem Van de Graaff with an energy of 5.6 MeV, about the average of the maximum energies of alpha particles from radium and its daughter products, was used to irradiate cells in vitro. The cells chosen for irradiation were a well characterized cell line[1] of normal mouse embryo fibroblasts (C3H 10T1/2). At the outset of the experiment, it was far from clear that any transformations would result because many previous workers had concluded that a single alpha particle hitting the cell nucleus anywhere had a high probability of killing the cell, thereby preventing it from becoming malignant.[2-6] However, in our preliminary work, this premise was found to be false in our particular experimental arrangement where the cells, as irradiated, were greatly flattened. Under these conditions, ten or more alpha particles passing through the nucleus were found to be equivalent to the mean lethal dose.[7,8] Our experiment did, however, simulate very well the cell geometry on bone surfaces, where the cells have been shown to be similarly flattened.[9,10] Encouraged by these early results, the experiments described here were continued.

## Methods and Materials

### Cells and Culture

The cell line (10T1/2, clone 8), chosen for this experiment, was kindly provided by Dr. Charles Heidelberger. Cells were grown in Eagle's basal medium containing 10% fetal bovine serum and 1% gentamicin in Falcon plastic flasks (75 $cm^2$ area). The cells were maintained in a humidified incubator with an atmosphere of 5% $CO_2$ at 37°C. The stock solutions were fed twice weekly and transferred when semi-confluent.

### Transformation Assay

Cells were seeded in 5 ml of medium on 60 mm diameter Falcon plastic Petri dishes at different cell densities, depending on the radiation dose required. The cells were incubated for 24 hr. Just before irradiation, the medium was sucked off with a Pasteur pipette attached to a vacuum pump for 10 s. The culture medium was replaced immediately after irradiation and changed twice a week until confluence was reached (at about the end of the third week) and then once weekly thereafter, until termination of the experiment 6 weeks after irradiation. Control and experimental dishes were handled in the same manner. On termination of the experiment, dishes were washed in phosphate buffered saline fixed for 20 min with absolute methanol and then stained for at least 40 min with a solution of Giemsa stain in distilled water buffered with Hepes and finally rinsed with water and dried.

Transformed foci were scored according to the criteria outlined by Reznikoff et al.[11]

### Cell Survival

Separate plates were set up in each experiment for determining the cell survival. The number of cells plated was varied, depending on the dose. The original number was gauged from preliminary cell survival measurements to result in about 40 surviving colonies per 60 mm dish after irradiation. The number of colonies was counted 10 to 14 days after irradiation. The plating efficiency for each radiation dose was determined by dividing the number of surviving colonies by the number of cells plated. Cell survival was also determined by dividing the number of surviving colonies in the irradiated plates by

the number in the unirradiated controls.

Irradiation

The cells were irradiated with a parallel beam of α particles which had an energy of 5.6 MeV at the cell surface. The irradiation times varied from 2 to 25 s. Control plates were placed in the same position as the irradiated samples with the beam switched off.

Details of the experimental arrangement and its calibration have been described in an earlier report,[8] but for the sake of completeness, a diagram showing the essential features of the design is included here (Figure 1).

Soft Agarose Technique

Stock solutions of agarose, tryptose phosphate broth, and DEAE dextran were made up in sterile water, autoclaved and stored. These were made up as follows: 2.5 g of agarose (Sigma type II) in 200 ml water, 2.95 g dehydrated tryptose phosphate broth (Difco Bacto T.P.B.) in 100 ml water, and 50 mg of DEAE (Pharmacia Fine Chemicals) in 100 ml water.

The medium was prepared by adding 10 ml heat inactivated fetal bovine serum and 10 ml tryptose broth to 40 ml × 2 BME medium. This solution was warmed to 44°C and added to 40 ml of agarose stock solution (previously melted and heated to 44°C) to which 0.4 ml DEAE dextran had been added. A base layer was formed by pouring 7 ml of this complete medium into a 60 mm diameter plastic Petri dish and allowing it to set at room temperature for not more than one hour. The top layer, which contained the cells, was prepared by adding 1 ml of the cell suspension, containing $10^5$ cells/ml in BME medium at 37°C,

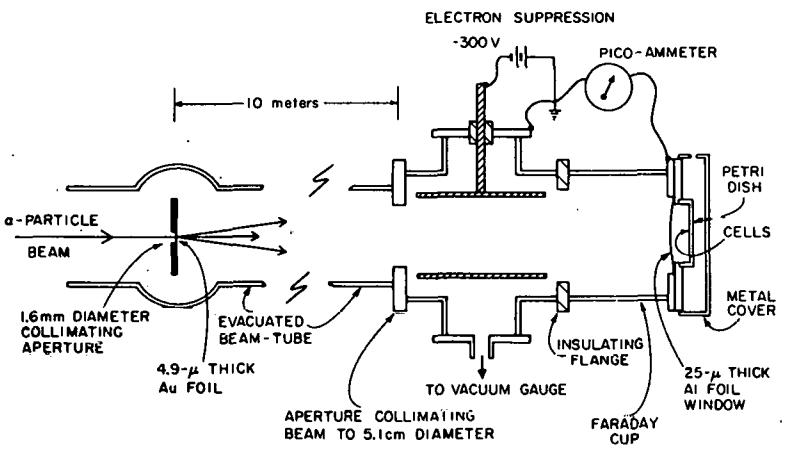


FIG. 1.--Schematic representation of the experimental arrangement used to irradiate the cells with α particles from a Tandem Van de Graaff machine. (ANL neg. 209-76-248 Rev. 1)

to 2 ml of the base layer material heated to 44°C. This was mixed by gentle swirling and poured on top of the base layer. The plates were incubated at 37°C in a humidified incubator containing 5% $CO_2$ and observed daily for about three weeks. To keep the agarose sufficiently moist, two or three drops of medium were added to the plates every three or four days.

Injection of C3H Mice

Ten six-week-old mice of the Heston strain (from which the C3H 10T1/2 cells were originally derived) were irradiated with 500 rads of 250 kv x rays to suppress the immune response. These were divided into two groups of 3 and another group of 4 animals. The first two groups were injected into the scapular region with cells derived from Type II and Type III transformed foci. The Type III cells were passaged five times in culture before injection, while the Type II cells were in their second passage. The third group of 4 animals was injected with normal control cells (passage 14). In each case, the injection consisted of $10^7$ cells in 0.5 ml of medium.

## Results

Cell Survival

Figure 2 shows the combined results of 6 different experiments in which the cell survival is given as the number of colonies found 10 to 14 days after irradiation, expressed as a percentage of the number in the control plates. The

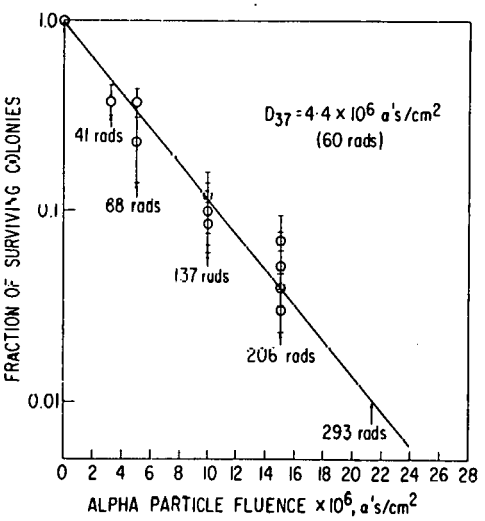


FIG. 2.--The number of cells surviving to form colonies expressed as a percentage of the number in the controls as a function of the alpha particle fluence. (ANL Neg. 149-77-173)

amount of radiation is expressed both in terms of alpha particle fluence and the average dose in rad using an LET value of 85 keV/μm for 5.6 MeV alpha particles. No correction was made for the loss of energy as the alpha particles passed through the cell layer because of the small thickness of the cell layer (2.2 μm) as demonstrated by electron microscopy.[8] As previously noted, the mean lethal dose for cell killing corresponded to the passage of 10 or more alpha particles through each cell nucleus in these cells which represented an average area of 313 $\mu m^2$ to the alpha particle beam.

Transformations

Three types of transformations, described by Reznikoff et al. as Types I, II, and III, were seen in the irradiated cells.[11] Only Types II and III were scored as transformants, since only these were found by others to be malignant when injected into syngeneic C3H mice.[11,12] Figures 3 and 4 show foci which were scored as Type II and Type III, respectively. The transformation frequency was expressed either as the frequency of transformed foci per irradiated cell or per surviving cell, based on the number of colonies. Figures 5, 6, and 7 show the transformation frequencies per irradiated cell as a function of α-

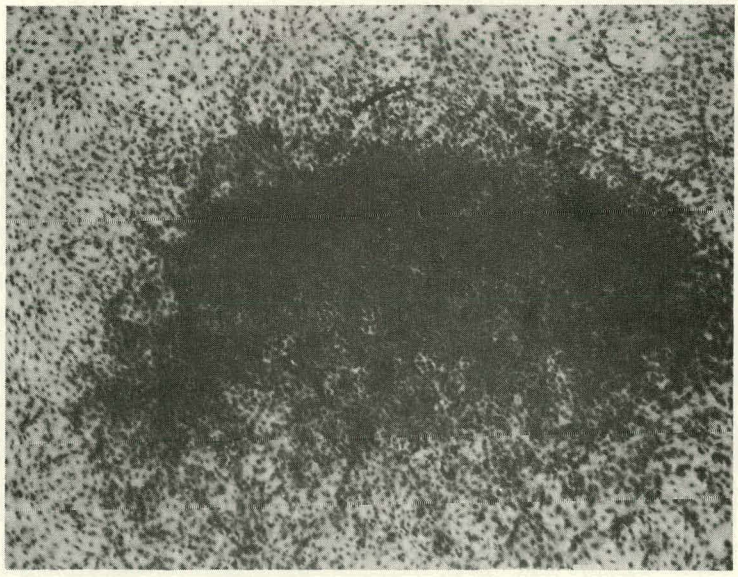

FIG. 3.--A Type II transformed focus of cells. Note the deeply stained piled-up appearance of the cells in the center of the picture compared to the normal cells outside the focus which are contact inhibited. (ANL neg. 149-77-328)

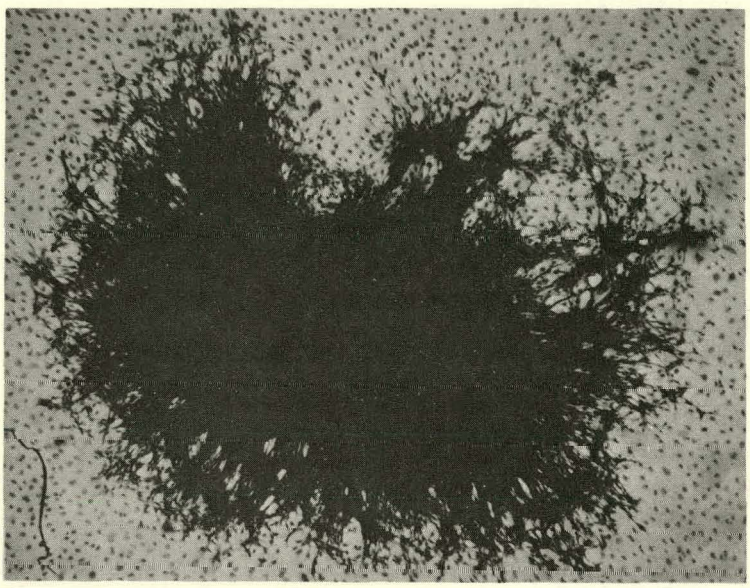

FIG. 4.--A Type III transformed focus of cells. This shows a piled-up area of cells with multiple crisscrossing of cells seen at the edge of the focus. This distinguishes it from the Type II focus seen in Figure 3. (ANL neg. 149-77-329)

particle fluence in three separate experiments. Both the frequencies and the fluences are plotted on logarithmic scales. The number of transformations scored at each point is indicated on the graphs. The data given in Figures 5–7 are replotted as the transformation frequencies per surviving cell in Figures 8–10.

Scanning Electron Microscope Studies

Normal cells, Type II, and Type III transformed cells were grown separately on glass coverslips. These were processed as described in an earlier report[13] and examined with the scanning electron microscope. As seen in Figure 11, the normal cells appear flattened and exhibit contact inhibition while the Type III transformed cells crisscrossed each other in a piled-up formation and exhibited more surface projections (Figure 12). The Type II transformed cells (not shown here) which were studied, exhibited an appearance more similar to the normal cells than the Type III cells.

Effect of the Number of Normal Cells on Focus Formation

In an experiment designed to elucidate the effect of the number of cells present on transformation frequency, normal and Type III transformed cells were

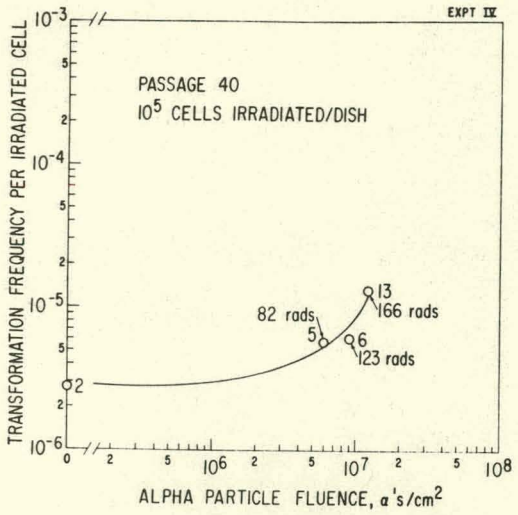


FIG. 5.--The transformation frequency per irradiated cell expressed as a function of α-particle fluence when $10^5$ cells (passage 40) per 60 mm diameter dish were irradiated. (ANL neg. 149-77-168)

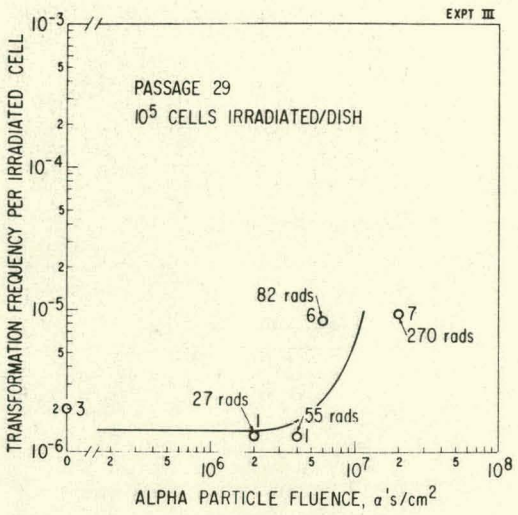


FIG. 6.--The transformation frequency per irradiated cell expressed as a function of α-particle fluence when $10^5$ cells (passage 29) per 60 mm diameter dish were irradiated. (ANL neg. 149-77-171)

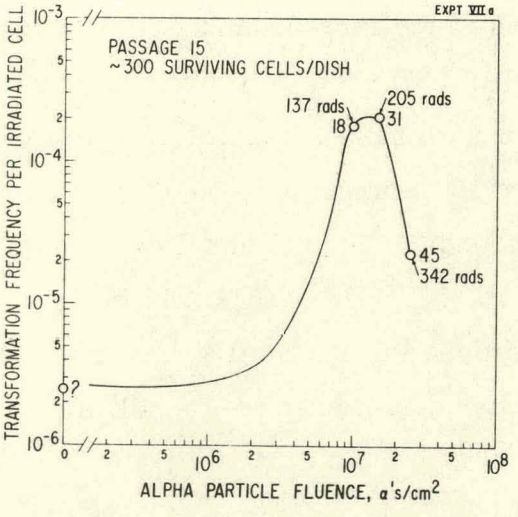


FIG. 7.--The transformation frequency per irradiated cell expressed as a function of α-particle fluence when cells (passage 15) were seeded at a density such that about 300 viable cells resulted per 60 mm diameter dish. (ANL Neg. 149-77-172)

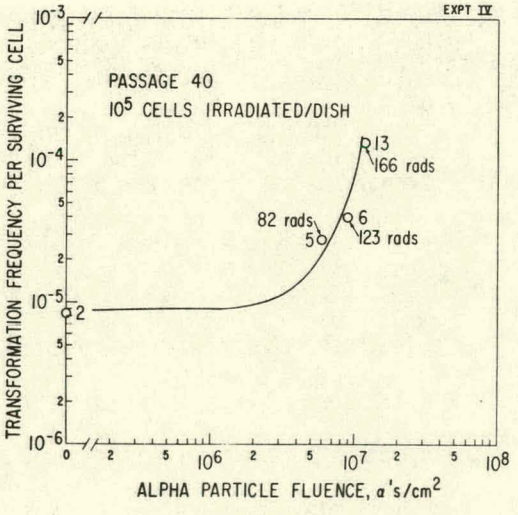


FIG. 8.--The transformation frequency per surviving cell expressed as a function of α-particle fluence when $10^5$ cells (passage 40) per 60 mm diameter dish were irradiated. (ANL Neg. 149-77-174)

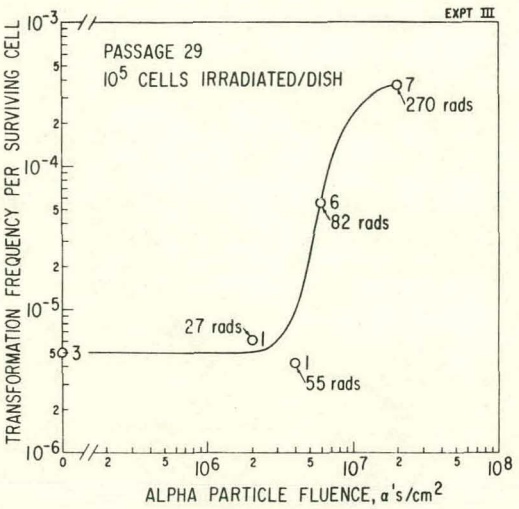


FIG. 9.--The transformation frequency per surviving cell expressed as a function of α-particle fluence when $10^5$ cells (passage 29) per 60 mm diameter dish were irradiated. (ANL Neg. 149-77-169)

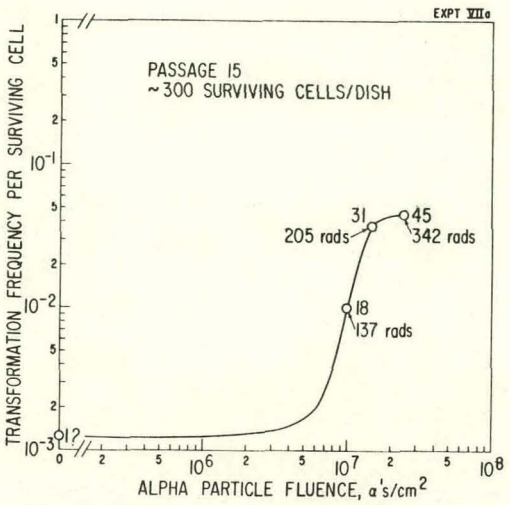


FIG. 10.--The transformation frequency per surviving cell expressed as a function of α-particle fluence when cells (passage 15) were seeded at a density such that about 300 viable cells resulted per 60 mm diameter dish. (ANL Neg. 149-77-170)

mixed in different ratios and subsequently scored for the number of foci in the way previously described. When 200 Type III transformed cells were mixed with an increasing number of normal cells in a 60 mm diameter dish, the number of transformed foci remained unchanged until $4 \times 10^3$ normal cells were added, although the morphology of the foci became more like Type II and Type I with the addition of increasing numbers of normal cells. When $1.7 \times 10^4$ cells were added, the efficiency of foci formation dropped dramatically from about 30% to about 2%. With this mixture of cells, the foci were extremely small and appeared only semitransformed.

Virus Studies

Transmission electron microscope studies of both Type II and Type III transformed cells failed to show any viral particles. In addition, tests for reverse transcriptase in the supernatant from normal and Type III transformed cells produced negative results.[14]

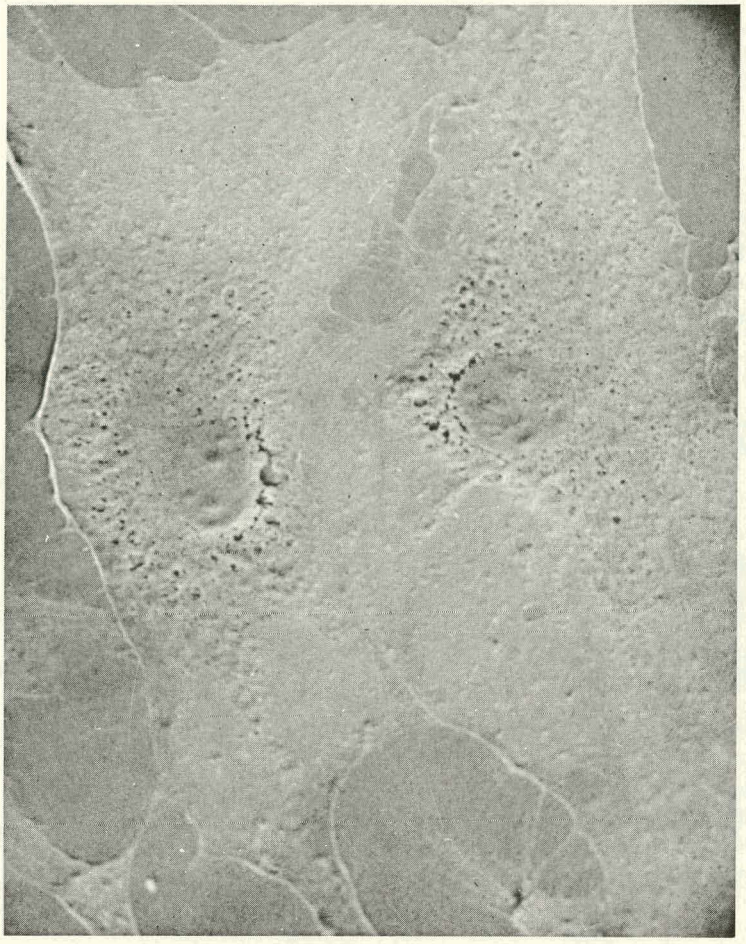

FIG. 11.--Scanning electron microscope picture of two normal cells which are contact inhibited (× 2090). (ANL Neg. 149-77-421).

Growth in Semisolid Medium

Probably the best in vitro test for the malignant potential of cells in culture is demonstrated by the ability of transformed cells to grow in a semisolid medium, demonstrating their anchorage independence. Figure 13 shows the appearance of colonies of cells in soft agarose which were grown up (passage 5) from a Type III transformed colony. In two separate experiments where $10^4$ and $10^5$ cells were used, 25% and 12% of the cells were shown to form colonies of 100 cells or more. The colony forming efficiency of Type II transformed cells (passage 2) was much less being 0.1% when $10^5$ cells were plated. Figure 14 shows the appearance of normal cells seeded at the same cell density as those shown in Figure 13. After an extensive search, no colonies representing more than one or two doublings were ever seen with the control cells.

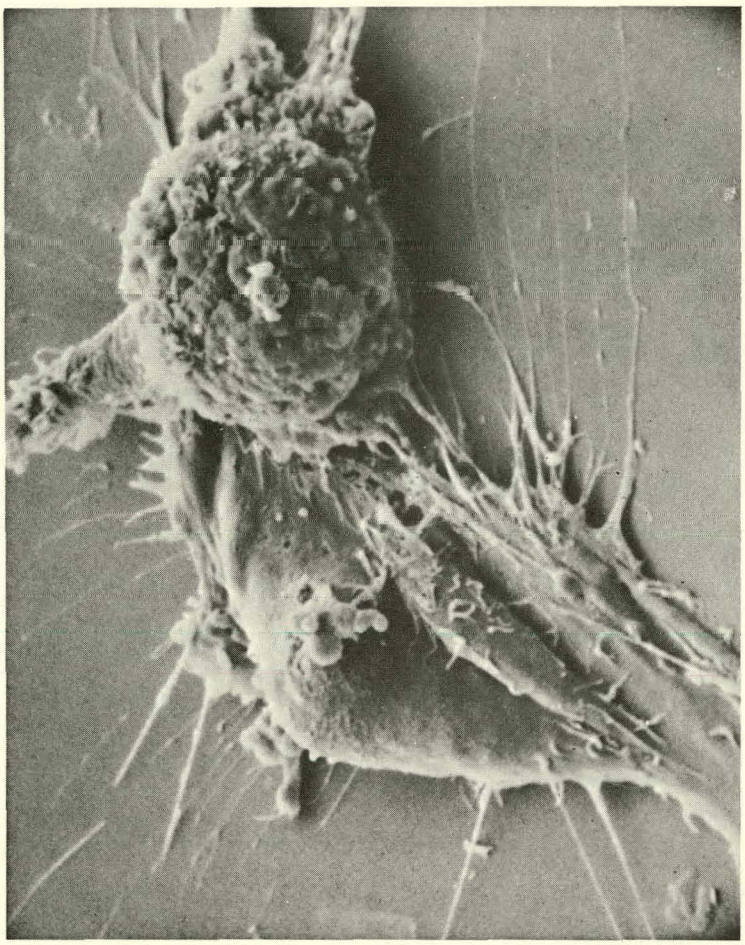

FIG. 12.--Scanning electron-microscope picture of Type III transformed cells showing cells with many surface projections piled up on each other (× 6480). (ANL Neg. 149-77-421)

Colony Formation

Figures 15 and 16 show the difference between the appearance of colonies of normal and transformed cells (Type III, passage 5) when 200 cells were seeded onto 100 mm diameter plastic Petri dishes and incubated for 12 days before staining. The colonies of normal cells are seen, in general, to be larger, more uniform and less densely staining than the transformed cells. The morphology of the individual cells within such colonies is also quite different, as illustrated in Figures 17 and 18.

Tumorigenicity of Transformed Cells

Two of the three mice injected with Type III transformed cells (passage 5) developed tumors at the site of inoculation 7-1/2 weeks after injection (Figure 19). On histological examination, both were classified as invasive fibrosarcomas. The third mouse that was injected with the same inoculum died after 16 days with a subdural hemorrhage, probably as a result of the prior

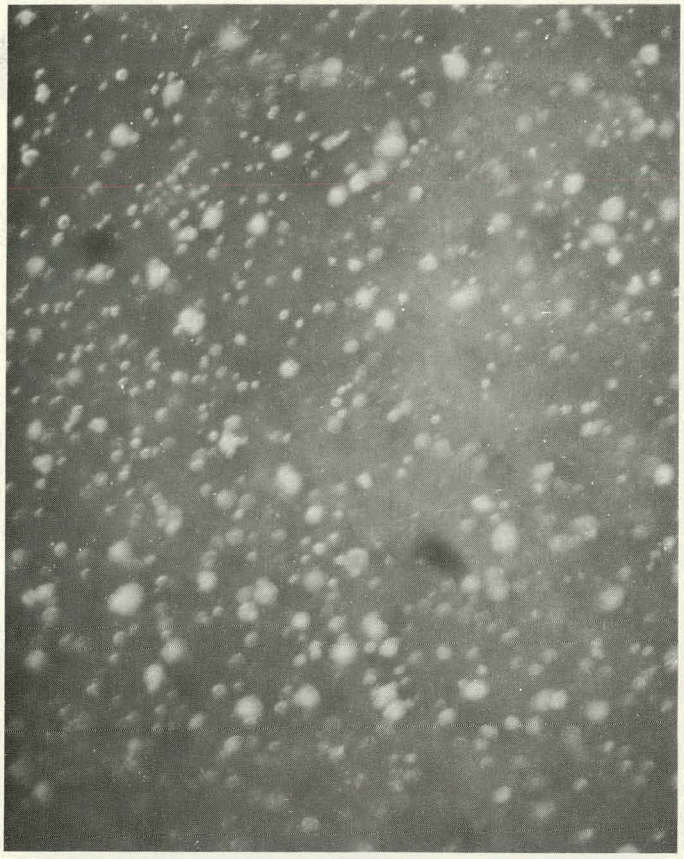

FIG. 13.--Light microscope picture of Type III transformed cells growing in agarose × 25. Note the discrete colonies of cells measuring up to 5 mm in diameter in some cases.
(ANL Neg. 149-77-331)

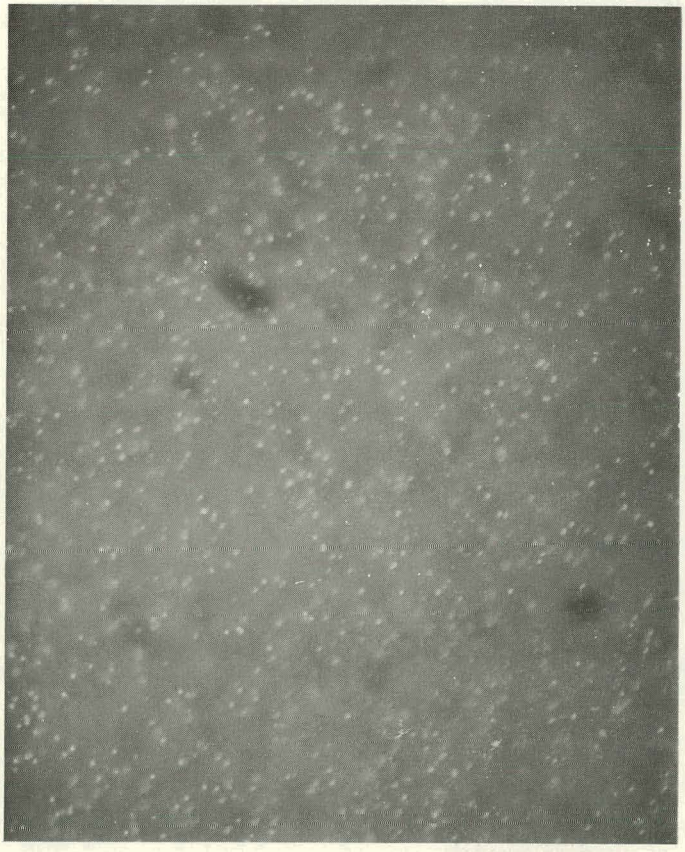

FIG. 14.--Light microscope picture of normal cells in agarose showing individual cells which did not form colonies in contrast to the transformed cells (Figure 13 × 25).
(ANL Neg. 149-77-330)

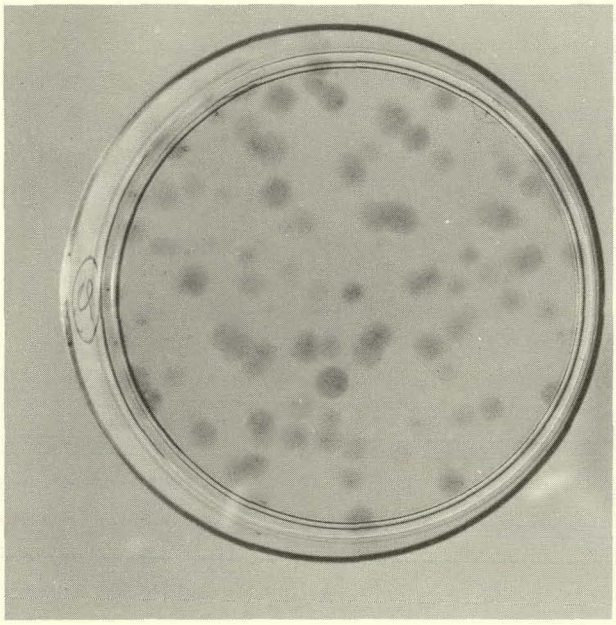

FIG. 15.--Light microscope picture of colonies of normal cells on plastic when 200 cells were seeded on a 60 mm diameter dish (× 1). (ANL Neg. 149-77-94)

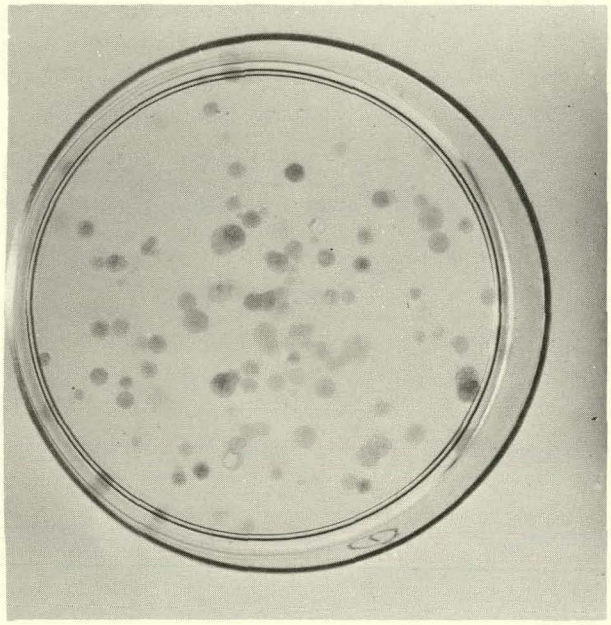

FIG. 16.--Light microscope picture of colonies of Type III transformed cells when 200 cells were seeded on a 60 mm diameter plastic dish. Note the variation in size of the colonies compared with the normal cells (Figure 15, × 1). (ANL Neg. 149-77-94).

irradiation dose used for depression of the immune response. However, removal of a very small portion of nodular tissue (about 2 $mm^3$) from the injection site revealed what appeared to be premalignant cells on histological examination. At 4 months, the mice injected with Type II (passage 2) transformed cells and normal cells (passage 14) appeared free from tumors.

Viral Transformation of Cells

Viral transformation of cells which were seeded at $10^5$ cells per 60 mm diameter dish was accomplished by adding an FBJ viral preparation, which was originally developed from a spontaneous osteosarcoma in a CF1 mouse.[15] The cells were fed and maintained as described for the irradiation experiments. On staining after 6 weeks, the transformations obtained in the virally infected cells all appeared alike, showing a swirling formation of the cells (Figure 20). This appearance was distinctly different from the large piling up and crisscrossing

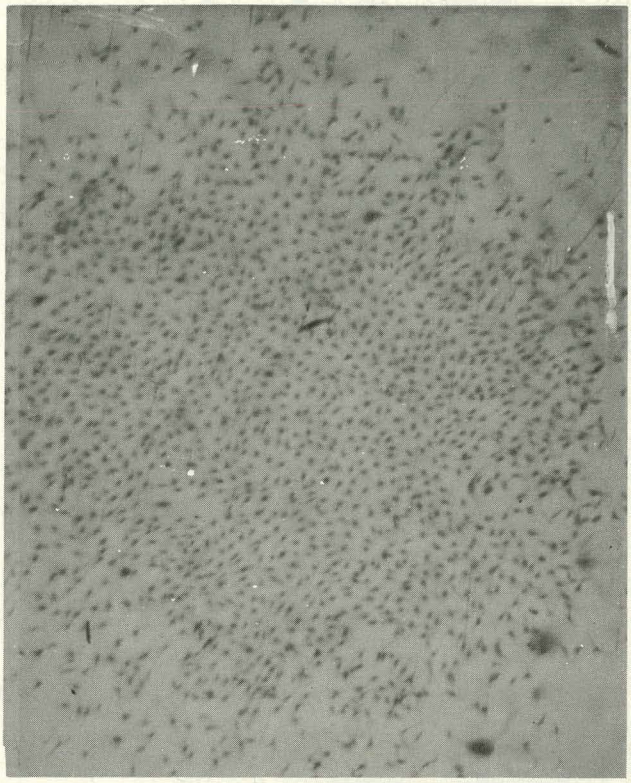

FIG. 17.--Light microscope picture showing the individual cells as they appear in a normal colony on a plastic Petri dish such as those seen in Figure 15 (× 25). Note the regular pattern of contact inhibited cells in contrast to the crisscrossing, piled-up appearance of transformed cells seen in Figure 18.
(ANL Neg. 149-77-92)

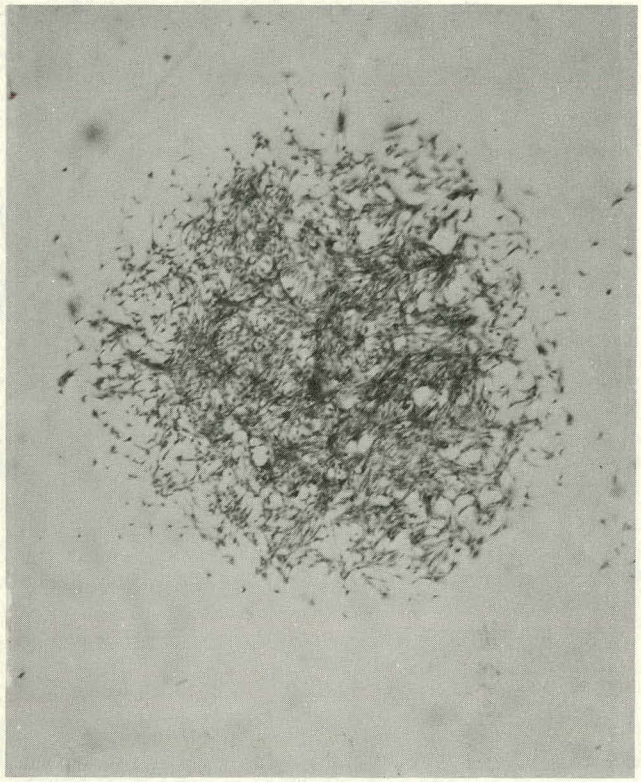

FIG. 18.--Light microscope picture showing the individual cells as they appear in a Type III transformed colony, such as those seen in Figure 16. Note the spindle-shaped cells which show a general disorganization compared with the normal cells (Figure 17).
(ANL Neg. 149-77-92)

of cells characteristic of the Type II and Type III foci seen after irradiation. The individual cells transformed by virus were elongate, spindle shaped, and had densely stained nuclei and cytoplasm, the latter being characteristic of transformed cells. No attempts were made to test their tumorigenic potential in mice. No transformations were observed in any of the control plates.

## Discussion

Mammalian cells in culture have been shown here for the first time to be transformed by α-particle irradiation. Malignant tumors were induced following

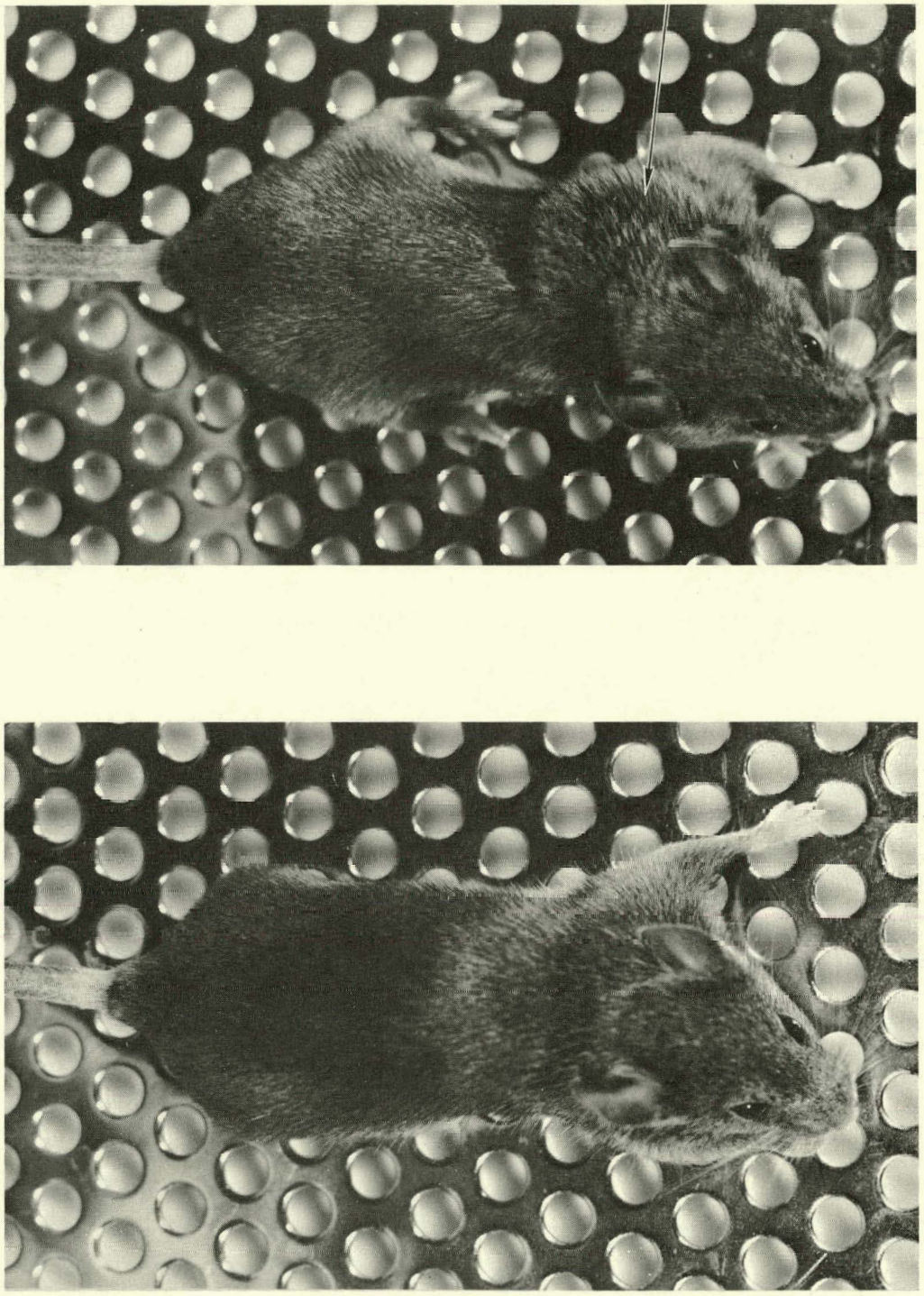

FIG. 19.--Picture showing two mice. One was injected with $10^7$, Type III transformed cells which gave rise to a tumor at the site of injection in the subscapular region. The other was injected with $10^7$ normal control cells and appears normal.
(ANL Neg. 149-77-296)

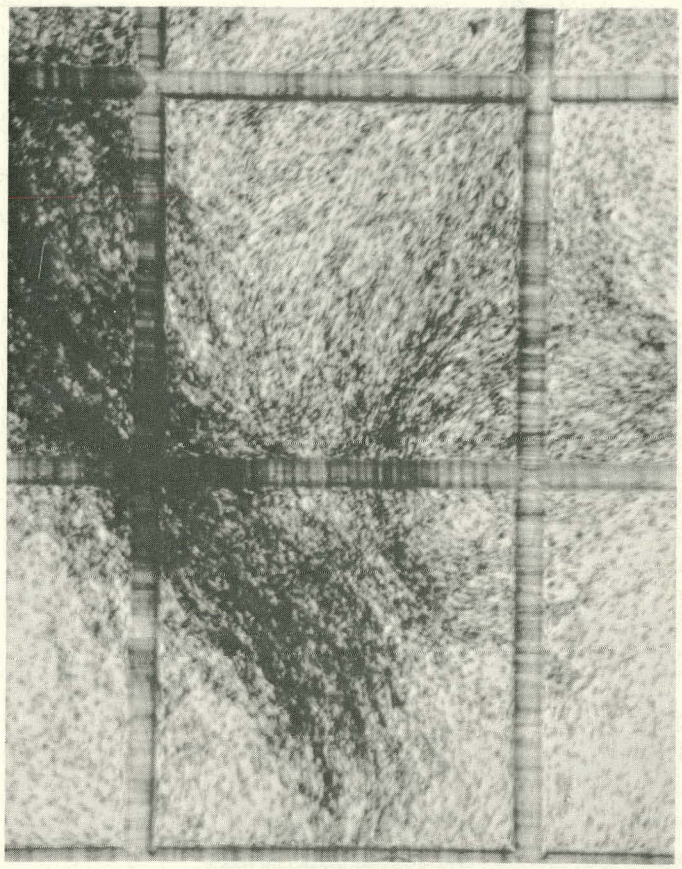

FIG. 20.--Picture showing a FBJ virus transformed focus (× 25). Note the difference in morphology between this focus and the Type II and Type III foci resulting from α-particle irradiation (Figures 3 and 4). (ANL Neg. 149-77-344)

injection of the transformed cells into immunodepressed mice. Unirradiated control cells injected at the same concentration failed to produce any tumors—at least up to the end of our current observation period of four months following injection. So far, we have only produced tumors from Type III and not from Type II transformed cells. However, this might have been expected since the particular Type II transformed cells which were injected had a poor colony forming efficiency in soft agarose. Other workers have shown a tight correlation between tumorigenic potential of mouse cells and growth in semisolid medium.[16]

In nine separate irradiation experiments involving 765 plates, of which 580 were irradiated (the rest being unirradiated controls), the transformation frequency was found to increase rapidly with dose. The maximum recorded was 4% of the surviving cells at an α-particle fluence of 1.5 to 2.5 × $10^7$ α particles/$cm^2$ (205–342 rads; Figure 10). Although the absolute values for

the transformation frequency varied with the experimental conditions used in each experiment, the general shape of the dose response was the same throughout. In the present study, no transformations were observed above background for α-particle fluences less than $6 \times 10^6$ α-particles/$cm^2$ (82 rads). This corresponds to 20 α particles passing through each nucleus. However, further work needs to be done to establish this lower limit.

The frequency of transformation appeared to vary most with the number of cells per dish irradiated. When the number of cells was changed from $10^5$ cells per dish to a number calculated to obtain 300 surviving cells based on the cell survival measured for each dose, the transformation frequency increased by more than an order of magnitude.

The increased transformation frequencies observed when smaller numbers of cells were irradiated with x rays has already been commented on.[12] This has been attributed to the increased ability of cells to manifest the transformed state when sparsely seeded. Terzaghi and Little found one order of magnitude decrease in transformation frequency when the cell density was changed from 400 cells to 1000 cells per 100 mm dish. At a cell density of 400 cells/100 mm diameter dish, the mean distance between cell centers is about 4.5 mm and for 1000 cells/100 mm dish about 2.8 mm. Since the cells are still widely spaced when seeded at 1000 cells per 100 mm dish, a direct cell-to-cell contact cannot be the reason for the decreased transformation frequency. The effect may be associated with the presence of some substance or substances secreted by normal cells which reduces the growth of transformed cells. Normal cells show optimum growth in medium conditioned by secretory substances previously elaborated by other normal cells. Experiments in which we have varied the ratio of normal to transformed cells growing together have resulted in a reduction of the number of transformed colonies as the proportion of normal cells increased. This strongly suggests positive restraints imposed by normal cells on the proliferation of transformed cells in the vicinity—an attribute often thought to be unique to the immune system in vivo and, in general, overlooked in models of carcinogenesis. Such restraints may explain the much lower transformation frequencies in vivo over those obtained in vitro. This

factor, with its implications for carcinogenic mechanisms, will be the subject of a future publication.

Another factor which appeared to alter the transformation frequency was the number of times the cells were passaged—cells in the later passages exhibited a higher background of spontaneous, but fewer radiation-induced, transformations. In the current work, only cells passaged less than 15 times are used. The use of a small number of cells on each of a large number of plates also limits the possibility of counting satellite colonies. Other factors which have been shown to affect transformation frequency are the quality of the serum and the temperature when irradiated.[17,18]

Despite all these variables, the shapes of the dose response curves found for the different experiments show the same general features as have been described for x-ray transformations using the same cell line.[12] The most notable differences are the steeper increase with dose, the increased peak frequency (about an order of magnitude higher with $\alpha$ radiation) and the smaller width of the peak, when the results are expressed as transformation frequency per irradiated cell, as in Figure 7. The latter reflects the steeper dose response for cell killing by $\alpha$ particles. When the results are expressed as transformation frequency per surviving cell, as seen in Figure 10, the frequency remains approximately constant above $1.5 \times 10^7$ $\alpha$ particles (205 rads). This corresponds to a similar finding with x rays where the plateau was reached at 400 rads.[12]

It is interesting to note that the heterogeneous morphology of the transformation seen here with $\alpha$ particles is remarkably similar to what has been observed with transformation of the same cell line by different chemical agents[11] and with x rays.[12] This was characteristically different from the homogeneous character of the transformed foci by FBJ virus, and might suggest different mechanisms of action.

The results presented here exhibit a marked degree of correlation with results obtained previously by other workers using the same cell line with different carcinogens; however, the results with other cell systems, such as the hamster embryo cell system, are remarkably different.[19] In particular,

the transformation frequencies with the hamster embryo cells appear to be more than an order of magnitude greater for x rays, where transformations were reported at doses as low as 1 rad. In addition, the shape of the dose response curve was much less steep in the hamster system, being indistinguishable from linear compared with an increase with the approximate square of the dose seen with the 10T1/2 cells with x rays[12] and the nearly cubic dose response seen here with α particles.

This points up the need for experimentation with normal human cells, which appear to have a greater ability to repair radiation damage than other mammalian species.[20] Experiments with the same experimental arrangement as described here, using normal human cells, are currently in progress. Early observations suggest we have already produced transformations in this system, but the results await confirmation.

Acknowledgements

We are grateful to C. A. Reilly, E. W. Chan, and C. K. Lee of the Virology group, who injected our cells with FBJ virus and maintained them for us in their laboratory. We are also grateful to E. W. Chan for carrying out the reverse transcriptase measurements. The histological examinations of the tumor material were carried out by R. J. M. Fry, to whom we are also grateful. The electron microscope studies were performed in the Biology Division.

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# A REPRODUCIBLE MICROTECHNIQUE FOR MEASURING STIMULATION OF HUMAN LYMPHOCYTES BY PHYTOHEMAGGLUTININ

K. E. Willard* and E. L. Lloyd

Methods based on tritiated thymidine incorporation were used for studies on the blastogenic transformation of human lymphocytes by phytohemagglutinin (PHA) in vitro. A stimulation index was calculated as the ratio of the radioactivity measured in lymphocytes to which PHA had been added to that in similar samples from which PHA was omitted. The stimulation indices have been shown to be reproducible to within 10% for the same individuals sampled at different times. The maximum mitotic indices for normal control subjects varied from 249 to 340. Seven to 11 different concentrations of PHA were used with each blood sample tested. The maximum index occurred, for most samples, at concentrations of PHA between 0.0625 μl and 1.0 μl/well. A systematic decrease in the maximum mitotic indices was found with increasing age in the range tested (19 to 58 years). Measurements of the single radium case 03-416, aged 70, with a residual body burden of 1.0 μCi $^{226}Ra$ gave a maximum value for the mitotic index of 44 at a concentration of 0.25 μl/well. This was a factor of 5 less than the value expected from our normal control subjects.

## Introduction

Mitogen-induced DNA synthesis is frequently used as a measure of lymphocyte immunocompetence. Lymphocyte responses to the T-cell (thymus-derived) specific mitogen phytohemagglutinin (PHA) provide a means of quantitating nonspecific cell-mediated immunity. This is a followup of a previous report[1] where measurements of lymphocyte stimulation in response to PHA were found to be irreproducible. The technique presented here not only shows reproducibility but also gives a higher yield of purified white blood cells and allows for more replicates to be done from the same initial volume of blood.

This technique is intended to establish a stimulation index showing the overall immunocompetence of the radium patients. This assay should provide a means of determining whether or not immunological impairment is a precursor to tumor development in patients predisposed to neoplastic disease because of

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a high body burden of radium. Immunosuppression has generally been observed in patients with neoplasia.[2] If serial sampling should show progressive loss in immunological competence, this might signal the onset of a malignancy at a time earlier than could be diagnosed by conventional methods.

## Methods and Materials

Human lymphocytes were purified from 10 ml of freshly drawn heparinized whole blood. The blood was centrifuged for 10 min at 170 g, the plasma was drawn off, and the remaining cells diluted with 10 ml of RPMI 1640 lymphocyte culture medium. This medium was prepared by adding 15 ml of a 1 M hepes buffer (GIBCO) and 5 ml of a 10 mg/ml gentamicin reagent solution (Schering Corp.) to 500 ml of RPMI 1640. Red blood cells were sedimented with 3 ml of a 2% methyl cellulose solution in normal saline for 20 min at room temperature. This sedimentation was accomplished by placing the diluted cell-methyl cellulose mixture in a 16 × 125 mm glass test tube and placing it at a 45° angle. The supernatant was drawn off and centrifuged to pellet the cells. Any contaminating erythrocytes were lysed using 5 ml of an ammonium chloride "shocking solution": 0.8% $NH_4Cl$, 0.1% EDTA Na3, 0.01% $KH_2PO_4$, pH 7.0 in distilled water. Cells were washed with phosphate buffered saline (PBS) and the purified white cells counted by the hemacytometer. Leukocytes were diluted to give a concentration of $4 \times 10^6$ cells/ml.

Leukocyte cultures were prepared in flat-bottomed microculture plates (CoStar) containing 0.2 ml culture medium made up as follows: 10 ml of medium contained 2 ml of heat-inactivated fetal bovine serum (FBS), 0.1 ml mercaptoethanol (stock solution of 0.5 M 2-mercaptoethanol buffer solution as supplied by Sigma Chemical Company and then diluted 1:50 in RPMI 1640) and 7.9 ml of RPMI 1640. 100 µl of this solution was dispensed per well to give a final concentration of $2 \times 10^{-5}$ M mercaptoethanol and 10% FBS in each well. PHA was diluted in RPMI 1640 to give the desired concentrations in 50 µl aliquots. PHA was added to test cultures in the following amounts: 8 µl, 4 µl, 2 µl, 1 µl, 0.5 µl, 0.25 µl, 0.125 µl, 0.0625 µl, 0.03125 µl, 0.015625 µl, and 0.0078125 µl per culture well. The final leukocyte concentration was $2 \times 10^5$.

cells in a total culture volume of 0.2 ml per well. Each test was performed in 3 to 6 replicate wells with a total incubation period of 72 hr. At the start of the last 18 hr, cultures were pulsed with 1 μCi/well of tritiated thymidine (55 Ci/mM) in 50 μl of RPMI 1640. Cells were harvested on glass filter strips utilizing a multiple automated sample harvester (MASH II), and washed with distilled water. Filters were cut, soaked overnight in 0.5 ml hyamine hydroxide, suspended in 10 ml of scintillation fluid, and subsequently counted using a Packard Tri-Carb Liquid Scintillation Counter.

## Results

### Stimulation Index in Different Individuals

Figure 1 shows the results of three separate assays done on subject 1, age 19. In the first assay, done on July 6, 1977, only seven doses of PHA were used, and it was not possible to determine if the peak response had been obtained. Therefore, the second assay, on July 27, 1977, was performed using a much wider dose range and a small plateau was found in the response between 0.125 μl and 0.25 μl PHA. As also shown in Figure 1, a third assay using this subject as a normal control for the radium patient gave results similar to the previous two assays. The maximum values for the indices were shown to be reproducible to within 10%. Figure 2 shows the results of two separate assays done on subject II, age 27, in which there is again reproducibility to within 10%. Figure 3 shows the difference in the dose spectrum for two other subjects, aged 41 and 58, the optimum stimulation indices being at 0.0625 μl PHA and 1.0 μl PHA, respectively.

### Comparison of Stimulation with Fetal Bovine Serum and Autologous Serum

Figure 4 shows the results of assays comparing the use of autologous serum with fetal bovine serum in two normal controls. In subject I, the response was the same for both sera within the standard error of the measurement, but with subject II, the FBS gave values for the maximum stimulation index which were about 25% higher than the autologous serum. This difference

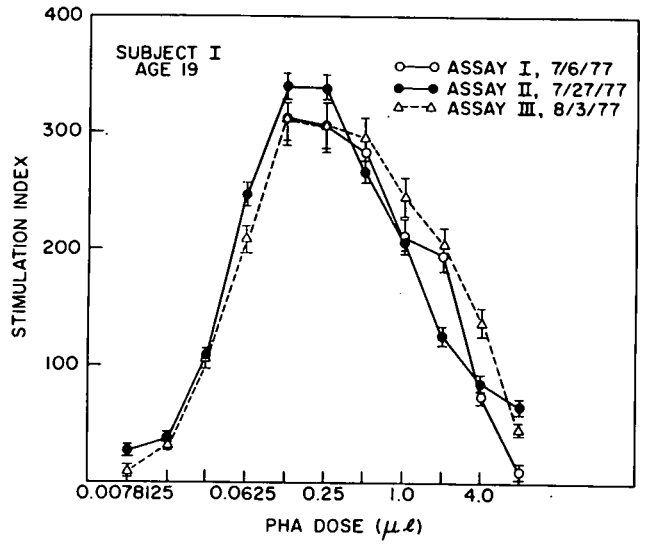


FIG. 1.--The effect of different concentrations of PHA on the stimulation of lymphocytes from subject I, age 19, using $^{3}$H-thymidine. The three graphs give the stimulation indices together with the standard errors for replicate samples of blood taken at three different times.

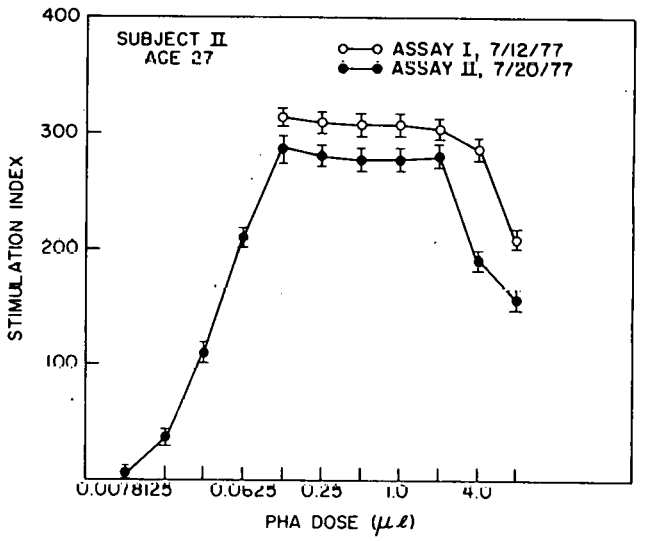


FIG. 2.--The effect of different concentrations of PHA on the stimulation of lymphocytes from subject II, age 27, using $^{3}$H-thymidine.

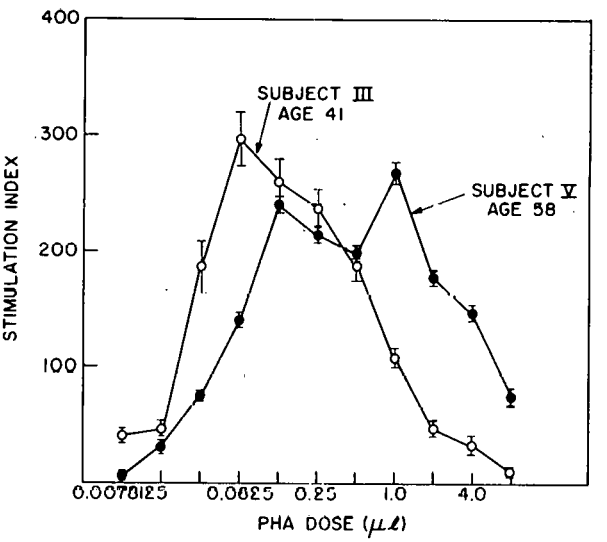


FIG. 3.--The effect of different concentrations of PHA on the stimulation of lymphocytes from subject III (age 41) and IV (age 58), using $^{3}$H-thymidine.

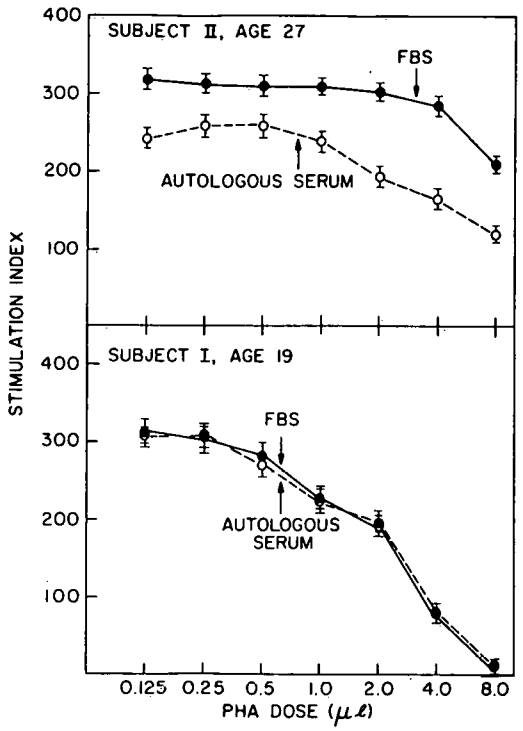


FIG. 4.--Graph comparing effects of autologous serum and fetal bovine serum on the stimulation of lymphocytes by PHA using $^{3}H$-thymidine uptake.

is somewhat greater than the reproducibility of the test carried out using FBS on the same subject at different times (Figure 2).

Stimulation Index of a Radium Patient Compared with Normal Controls

Figure 5 shows the spectrum of stimulation indices for radium patient 03-416, aged 70, who has a residual body burden of 1.0 μCi $^{226}Ra$ together with those for 2 normal controls of different ages. Leukocytes from the patient and the control subjects were processed simultaneously. A 5-fold increase in the stimulation indices of the control subjects over the radium patient can be seen, although the maxima occur with about the same amount of PHA (0.25 μl) in all three cases.

Stimulation Indices as a Function of Age

Figure 6 shows a composite plot of maximum stimulation indices obtained for all of the normal subjects tested in the age range 19 to 58, together with the value obtained for the 70-year-old radium patient. A systematic decrease in the mitotic indices was found with increasing age in the control subjects. The much lower value obtained for the radium patient may be the result of the use of the drug hydralazine hydrochloride (CIBA) which she is currently taking for the treatment of hypertension.

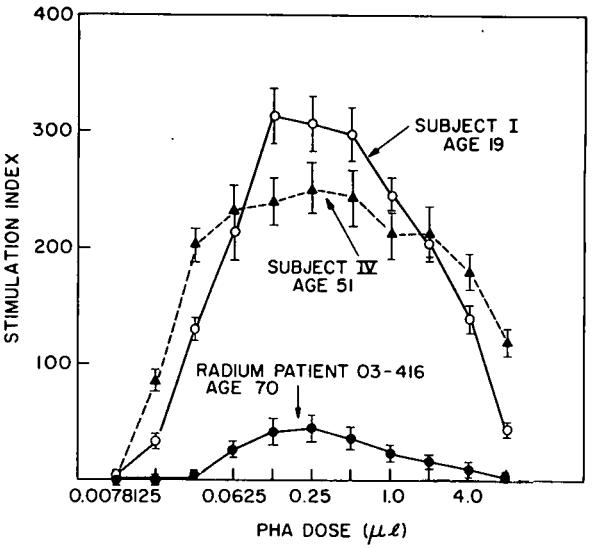


FIG. 5.--Comparison of the stimulation of lymphocytes from radium patient 03-416 and two normal controls by PHA using $^{3}H$-thymidine uptake

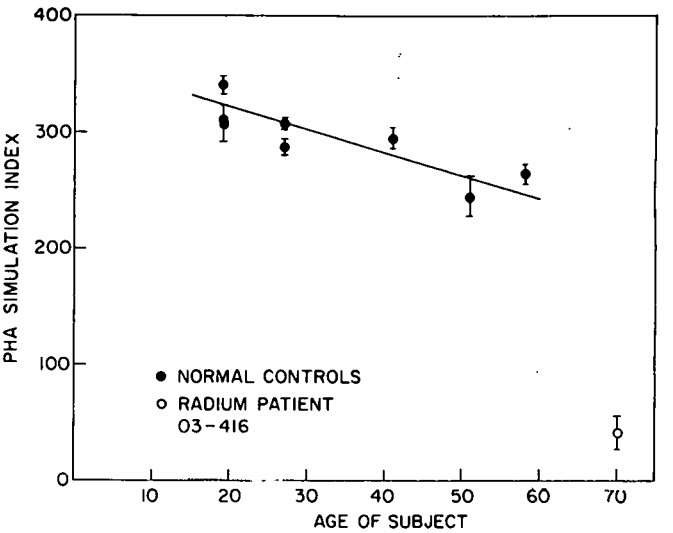


FIG. 6.--Graph showing the maximum stimulation indices for different subjects as a function of age.

## Discussion

The interaction of lymphocytes in culture and the kinetics of the reaction of activators, such as PHA with lymphocyte membranes, are complex and poorly understood. Variables such as the concentration of PHA, the ratio of PHA molecules to lymphocytes, the cell density, the presence of other blood cells, and the culture surface area all affect the kinetics and intensity of the response.[3] The time of detectable response and the peak of this response varies among individuals; however, the stimulation index at the optimal PHA dose gives reproducibility to within 10% for the same subject measured on different occasions.

Clearly, this assay for lymphocyte immunocompetence is more reproducible than the method reported earlier.[1] The importance of performing dose response curves on each individual is emphasized by the increase in stimulation over a small range of doses and the differences in the optimum dose for each individual. For all individuals, there was an approximately linear increase of incorporation of tritiated thymidine with increasing concentrations of PHA at low doses and a corresponding loss of label at the highest doses.

The decreased incorporation at both ends of the dose spectrum is probably due to the less than optimum concentration of mitogen at the low doses and the cytotoxicity of PHA at the high doses.

In studies using research animals, serum factors which enhance or suppress proliferation are encountered[4] and it is, therefore, thought to be important to test autologous serum. In normal subjects, it seem likely that the optimum expression of transformation depends on a balance between such factors. However, many cancer patients have been shown to possess suppressive factors in their serum.[5] In the two normal subjects tested here, the maximum stimulation indices differed by less than 30% with the FBS and autologous sera. Establishment of the consistency of this response using other control subjects would be worth while in determining a baseline for detecting an altered response in the radium patients.

Erythrocytes and monocytes have been shown either to stimulate or depress the T lymphocyte response to PHA depending on the ratio of their number to the number of lymphocytes present.[3] In the test described here, the addition of mercaptoethanol to lymphocyte cultures destroys the red cells, thus eliminating one variable due to the presence of different concentrations of these cells. It has also been found that mercaptoethanol helps to degrade the PHA and acts to enhance T-cell proliferation.[6] This is thought to be partly responsible for the increased consistency and the higher stimulation indices found here, compared with our previous studies.[1]

The length of incubation and time of radioactive pulse are also important. The label must be available at the time the lymphocytes are undergoing active DNA synthesis; however, it must not be too lengthy in order to prevent excess exchange of labeled precursor with the nonradioactive pool. The MASH unit overrides the difficulty found in previous techniques in inefficient recovery of the intact radiolabeled cells and eliminates the tedious manual operation of harvesting a vast number of samples. About 75 wells (6 replicates at each of 11 concentrations of PHA, plus about 9 control wells) were used for each 10 ml sample of blood. This repeated sampling, possible only with microtechniques, makes this method eminently suitable when only small samples of blood are

available, as in the radium cases. Further measurements with blood from the high radium burden patients using this test should enable us to establish whether or not there is correlation between general immunocompetence and radiation dose and allow us to detect any loss in immunocompetence by successive sampling from each patient.

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# IDENTIFICATION OF OSTEOSARCOMA CELLS IN CULTURE USING ALKALINE PHOSPHATASE

C. B. Henning and E. L. Lloyd

To provide a positive identification of osteosarcoma cells in culture after varying lengths of time in passage, four different techniques were used to detect, localize, and quantitate alkaline phosphatase. As far as is known, this is the first report of the use of an enzymatic marker for this purpose. Light microscopy gave a measure of the number of cells in each culture elaborating the enzyme. Transmission and scanning electron microscopy showed localization of the bone isoenzyme on cell surfaces. Quantitation of the enzyme was carried out with an automatic GEMSAEC fast analyzer. The relative merits of each method are compared and contrasted. Of the eight cell lines tested, all of which were originally derived from human osteosarcomas, five retained the alkaline phosphatase activity characteristic of the original tumor. Screening of this type will make immunological testing using osteosarcoma cells in culture more meaningful in the future.

## Introduction

Many studies have shown that radium patients with a high body burden are predisposed to certain tumors, such as osteosarcomas.[1] Attempts have previously been made to detect the presence of bone tumor antibodies in the blood of these patients in order to obtain an earlier diagnosis of the tumor.[2] This test requires the use of osteosarcoma cell lines which have retained their osteosarcoma antigens. Since cells in culture often lose many of their original characteristics, it is important to screen out those cells which are no longer immunologically reactive. There are many factors that can alter cultured cells, especially if maintained for long periods. Some of these are: 1) Adaptation to the artificial environment (i.e., growth on plastics in medium), 2) cell selection as a result of passaging in culture, and 3) genetic mutations of a minor or major degree that may even change cell type.[3] Morphology alone is not enough to distinguish osteosarcoma cells, since some of them may have the same morphological appearance as normal fibroblasts, which are the most common cells transferred with tumor material during initial culture. The test described here, using alkaline phosphatase activity, can make the important differentiation between normal fibroblasts, which may have overgrown the

culture, and osteosarcoma cells. Some of the tests have also been designed to show contamination by other cell types—in particular, contamination by HeLa cells.

The idea for staining the osteosarcoma cells in culture for alkaline phosphatase activity stemmed from the practice of staining histological sections of sarcoma tumors to distinguish between fibrosarcomas and osteosarcomas since osteosarcomas, in contrast to fibrosarcomas, produce osteoid and alkaline phosphatase activity.[3]

Alkaline phosphatase enzymes comprise a group of enzymes referred to as isoenzymes which, in the human case, are tissue specific for bone, placenta, liver, intestine, etc.[4,5] In the present report, the tissue culture cells were tested for the specific bone isoenzyme, which would be expected, from the site of the osteosarcoma tumor.

## Materials and Methods

### Light Microscope Technique

The cells were plated on Lab-Tek flaskettes in RPMI 1640 media plus 15% fetal bovine serum and incubated at 37°C in a humidified atmosphere of 5% $CO_2$ for one to seven days, depending on the test purpose. The cells were then washed in phosphate buffered saline and fixed in 10% neutral buffered formalin at 2 to 5°C for one-half hour. Following fixation, the cells were rinsed several times in distilled water and placed in the staining mixture. The staining mixture consisted of 48 ml distilled water, 2 ml of the naphthol AS-MX phosphate substrate (Sigma) and, optionally, two drops of manganese chloride activator (Sigma), which was initially stirred before adding 25 mg (or 12 mg fast violet B) of diazonium salt. The mixture was stirred again and filtered before use. The slides containing the cells were placed in this solution for 30 min at room temperature.

Two types of diazonium salts were tested. The fast violet B salt was found to be the best for light microscope use because it dissolved easily in the incubation mixture and gave a bright, easily distinguished, coarse end product. The fast blue BB salt, which required filtering, gave a more finely particulate

end product, which was more suitable for electron microscope localization.

A counterstain for the cell nuclei was found to be useful only for visualizing negative cells since counterstaining confused the pattern of staining in the osteosarcoma cells, which already showed a positive stain. Fast green, Mayer's hematoxylin, methylene blue, or safranin were used, depending upon which contrasted best with the azo dye used. The slides were then viewed and photographed, using a Leitz light microscope.

In order to differentiate between the placental type isoenzyme common in HeLa cells and bone isoenzymes, the slides containing the cells were heated at 56°C for 15 min. Under these conditions, the placental isoenzyme remains totally insensitive while the bone isoenzyme loses about 80% of its activity.[5,6]

Electron Microscope

For the electron microscope studies, the cells were grown on 60 mm diameter Falcon plastic Petri dishes or for the scanning electron microscope studies, on round glass coverslips. The cells were rinsed two or three times in 0.1 M cacodylate buffer. They were then fixed in 1.5% glutaraldehyde buffered with 0.1 M cacodylate buffer for one-half hour, followed by one hour in buffered 3% glutaraldehyde, both at room temperature. (This has been shown by others to decrease the enzyme activity somewhat more than the formalin used in the light microscope technique, but it preserves the cellular components much better.[7]) Following fixation, the staining for alkaline phosphatase was the same as for the light microscope. After this procedure, the Petri dishes containing cells for flat embedding in the transmission electron microscope work were processed by the same technique as described in a previous report.[8]

The cells grown on glass coverslips for scanning electron microscopy were processed as described in reference 9, following the enzyme staining.

Automatic GEMSAEC Fast Analyzer

To determine the decrease in isoenzyme activity with heat treatment, the alkaline phosphatase activity was measured quantitatively on an automatic GEMSAEC fast analyzer. Aliquots of medium were removed from confluent monolayers of cell cultures which showed positive staining with the slide technique, as well as from negative controls. The medium was then centrifuged

to remove cell debris, and one-half of each sample was heat inactivated in a water bath at 56°C for 15 min. After that, 0.5 ml of each sample was pipetted into each sample cup for measurement by the GEMSAEC fast analyzer.

The operation of this instrument depends on the reaction between the paranitrophenyl phosphate substrate and the alkaline phosphatase enzyme to form a yellow colored reaction product. This reaction is quantitated by measuring the absorbance increase at 405 nm over a known period of time.[10]

## Results

### Light Microscope

As seen in Table 1, a different proportion of cells stained in each of the 12 cell lines which were tested. Five of the eight cell lines which originated from osteosarcomas showed some proportion of stained cells. In one of these, SaOS, Figure 1, every cell stained. As expected, no stained cells could be seen in any of the normal fibroblast cultures (Figure 2). The cell line CCL5 (HeLa) showed the most intense staining of all the cell lines tested.

With the cell lines SaOS and CCL5 (HeLa) the color reaction could be seen by eye in the incubation mixture within approximately 60 s. The Te 85 cell line could be distinguished less easily after several minutes; the other cell lines tended to have fewer positive cells more randomly scattered.

SaOS and Te 85 cell lines showed that the staining intensity per reacting cell was related to cell density, as well as the length of time the cells were allowed to grow. Sparsely scattered cells reacted noticeably less intensely than more confluent cells stained at the same time intervals. This is probably related to the longer lag phase of sparse cells. In general, the stain intensity (i.e., alkaline phosphatase activity) per cell increased with time incubated in culture as has previously been reported for other human cell lines.[11]

No matter at what density the negative cells were plated, no cell showed any precipitation, as illustrated in Figure 2.

The stage of the cell cycle and the shape of the cell (rounded or flattened) made a difference in the intensity and distribution of the azo dye

Table 1. Alkaline Phosphatase Activity-Light Microscope Slide Technique

| Cell line code name | Passages tested | Cell type | Cell line description | Alkaline phosphate activity[a] |
|---|---|---|---|---|
| SaOS | 28-159 | Epithelioid | Osteosarcoma | ++ |
| U2 OS | 48-162 | Epithelioid | Osteosarcoma | 0 |
| AR 177 | 4-23 | Fibroblastic | Osteosarcoma | + |
| AT 610 | 6-16 | Fibroblastic | Osteosarcoma | + |
| AT 859 | 6-19 | Fibroblastic | Osteosarcoma | 0 |
| AQ 298 | 8-23 | Epithelioid | Osteosarcoma | 0 |
| H-25 | 7-14 | Fibroblastic | Osteosarcoma | +/0 |
| TE 85 | 26-92 | Epithelioid | Osteosarcoma | + |
| AW 995 | 19-54 | Fibroblastic | Normal newborn foreskin | 0 |
| NFS-1 | 21-22 | Fibroblastic | Normal newborn foreskin | 0 |
| CRL 1187 | 8-33 | Fibroblastic | Normal adult skin | 0 |
| CCL 5 (HeLa) | Passage unknown | Epithelioid | HeLa overgrown | +++ |

[a] Grading system: 0, No cells staining; +/0, a few positive cells; +, a fair number well stained; ++, every cell staining positive to varying degrees; +++, every cell positive, many with extremely heavy precipitate.

precipitation on the surface of the cells. The more rounded cells, such as those seen in the epithelial cell types, SaOS, TE 85, and CCL5 (HeLa), showed an intense piling up of the dye in the nuclear area, while the more flattened cells showed a lighter, more evenly distributed stain over the entire cell surface. The positive fibroblastic cell type, such as that seen in AR 177, occasionally revealed a more intense pattern in the perinuclear area, but usually, the staining was quite uniform. Those fibroblastic cells which stained positively were found to be randomly dispersed even when allowed to incubate for a week and pile up. On the other hand, when Te 85 cells, which have an epithelial morphology, were allowed to grow to confluence, the intensely stained cells formed distinct patches among the negative areas. This particular cell line showed an increased number of positive staining cells with

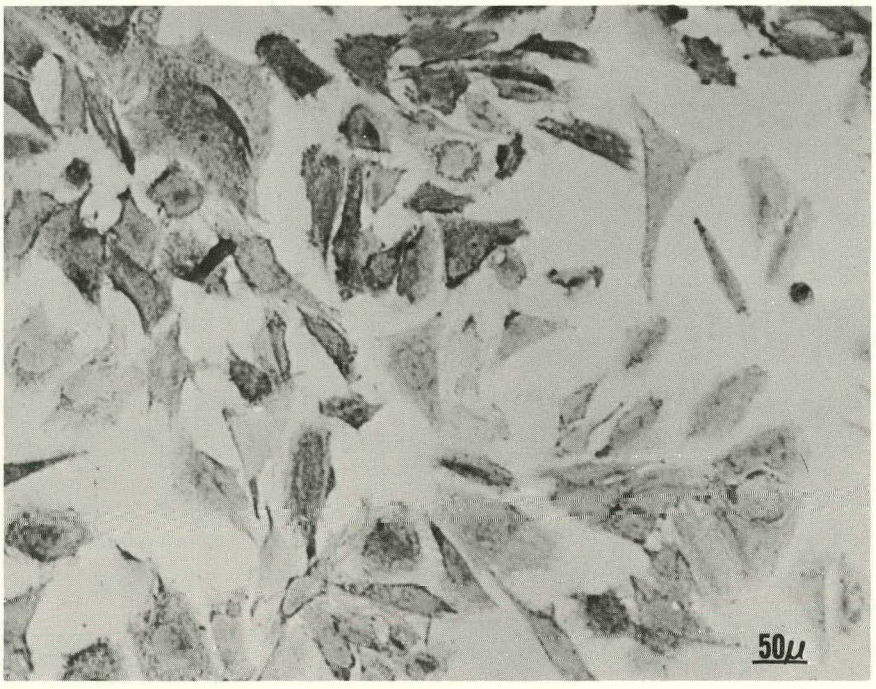


FIG. 1.--Light microscope picture of osteosarcoma cell line SaOS, showing all of the cells stained with alkaline phosphatase at various intensities.

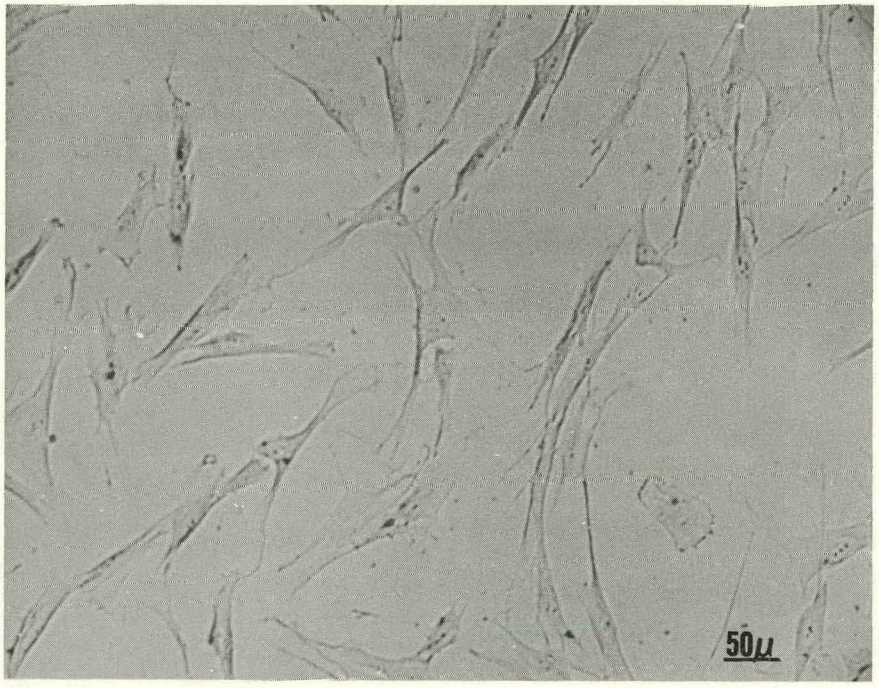


FIG. 2.--Light microscope picture of normal control fibroblast AW995, showing no alkaline phosphatase staining.

increasing passage numbers over the year it had been tested. Attempts to clone the positive staining cells are in progress.

The increased staining intensity after a week of growth was seen in all cells. Hence, the cells were grown for a week on the slides which were used for the differentiation of the isoenzymes by heat treatment as described. Following treatment, CCL5 (HeLa) was found to be the only cell line which showed no decrease in stain intensity. The osteosarcomas SaOS, Te 85, AR 177, and AT 610 showed a definite decrease. These results are consistent with the presence of the stable placental type isoenzyme on the HeLa cells and the heat labile bone isoenzyme present in the other cultures.[5]

One of the interesting results was the presence of alkaline phosphatase in the osteosarcoma cultures with fibroblastic morphology. There are two possible alternatives to explain this result. Either such a fibroblastic cell has already changed metabolically in preparation for its morphological differentiation into an osteoblastic cell[12] or it is the end result of an osteoblastoid cell mutating to a fibroblastic morphology but retaining some osteoblastoid activity.[3]

Electron Microscope

Previous work by others with the electron microscope has shown that the HeLa placental type isoenzyme is localized at the surface of the plasma membrane of the cell. Nuclear localization has been specifically ruled out by painstaking subcellular fractionation techniques.[13] Since the location of the bone isoenzyme has hitherto been unknown, both scanning and transmission electron microscope studies were undertaken in the present study to see if the bone isoenzyme had a characteristic localization similar to, or different from, the placental type isoenzyme.

As one can see from the scanning electron micrographs of CCL5 (HeLa) and SaOS (Figures 3 and 4), there is no apparent difference in the localization of the two isoenzymes, except that HeLa shows a stronger precipitation reaction. When the more finely particulate Fast blue BB type of azo dye was used, one can see the activity on the cellular extensions (Figure 5) as had been reported for more flattened cells, using a lead phosphate technique.[14] The heavier activity

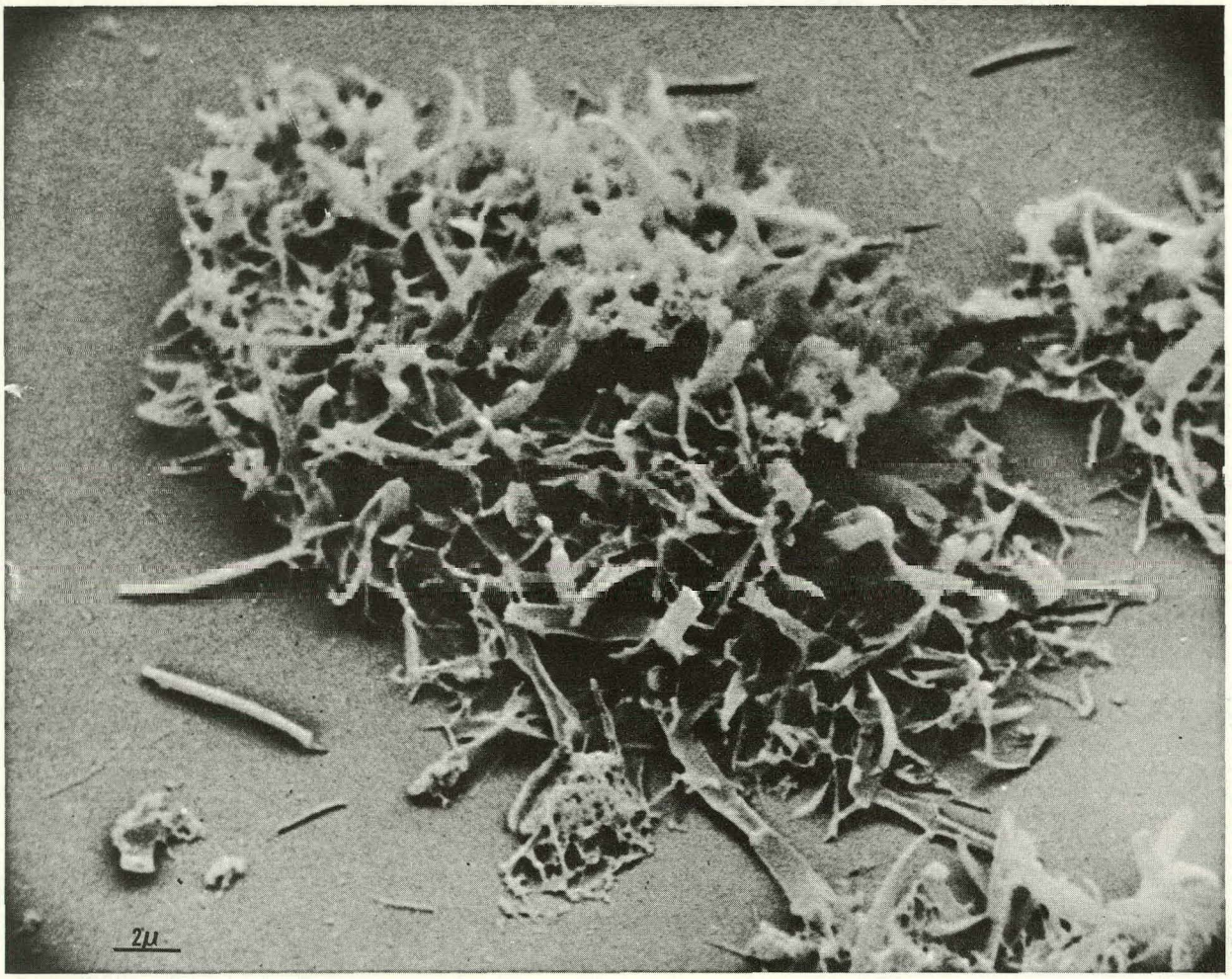


FIG. 3.--Scanning electron microscope picture of CCL5 (HeLa), showing intense alkaline phosphatase staining over the complete surface. The numerous projections completely masking the cell's surface are the deposits of the fast violet B salt.

over the nuclear area is still common in more rounded cells. The flattened cells do not show as great a precipitation over their total surface, even when the activity in the filopodia extensions is taken into consideration. This may indicate a greater production of alkaline phosphatase in the rounded cells due, possibly, to their stage in the cell cycle. It may merely indicate a more metabolically active cell, with the alkaline phosphatase sites on the membrane concentrated over the nucleus.

The use of organic solvents (and in TEM, epoxy resin) in the preparation of the samples removed a considerable amount of the stain; however, identical

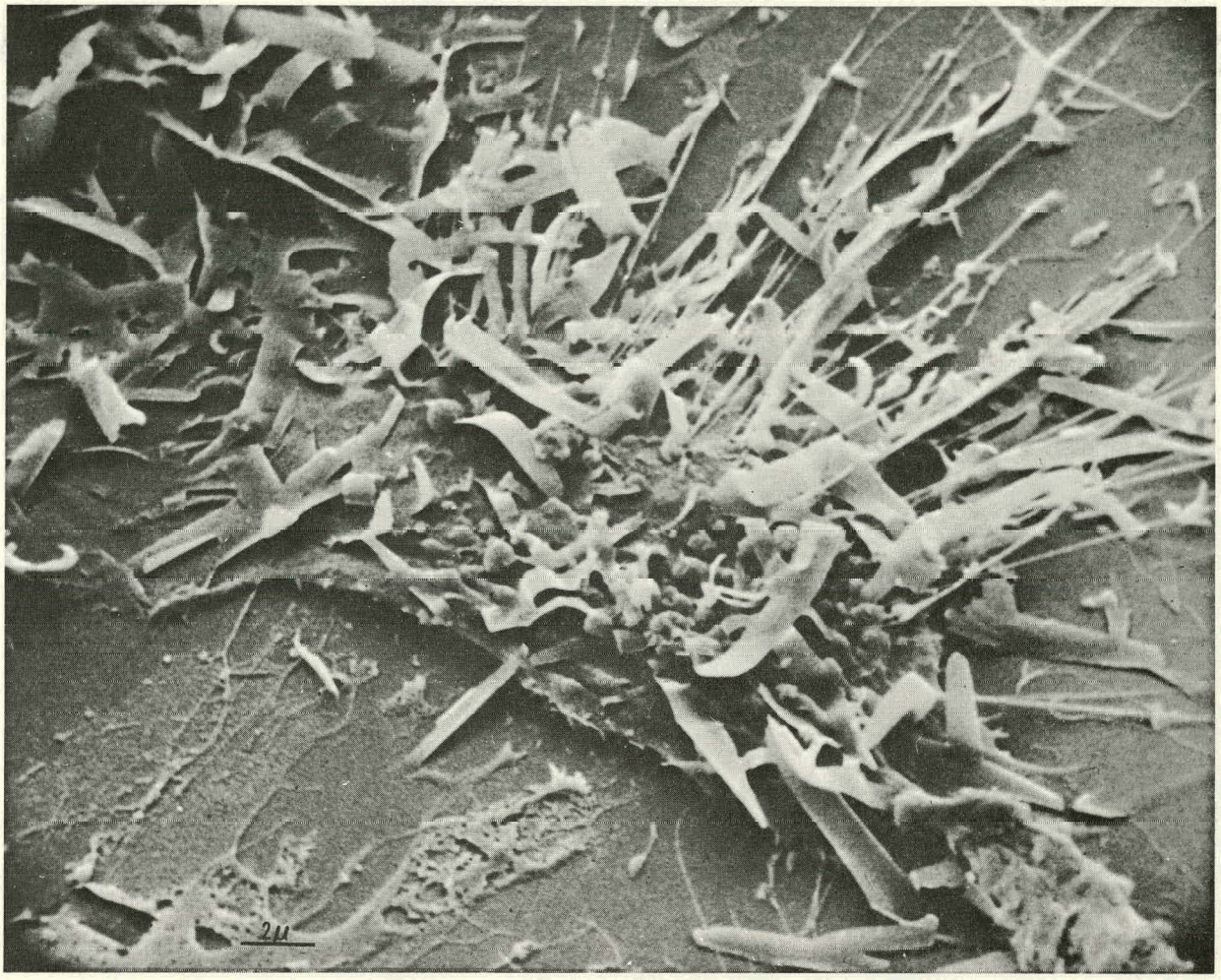


FIG. 4.--A scanning electron micrograph of a positively stained (SaOS) osteosarcoma cell illustrates the coarse deposits of fast violet B salt over the cell surface.

sample treatment allowed comparative evaluations of different cell lines.

The transmission electron microscope results of the fast violet B type of azo dye in the SaOS cell line (Figure 6) showed a coarse, dark crystalline precipitate only at the plasma membrane, although other sites that stained less intensely may have lost their label during specimen preparation.

The negative controls for the EM preparations (Figure 7) were placed in an incubation mixture with everything present except the substrate to check for nonspecific precipitations of diazo salts. A negative control fibroblast culture NFS-1 was incubated in the complete reaction mixture and showed no precipitation on its surface.

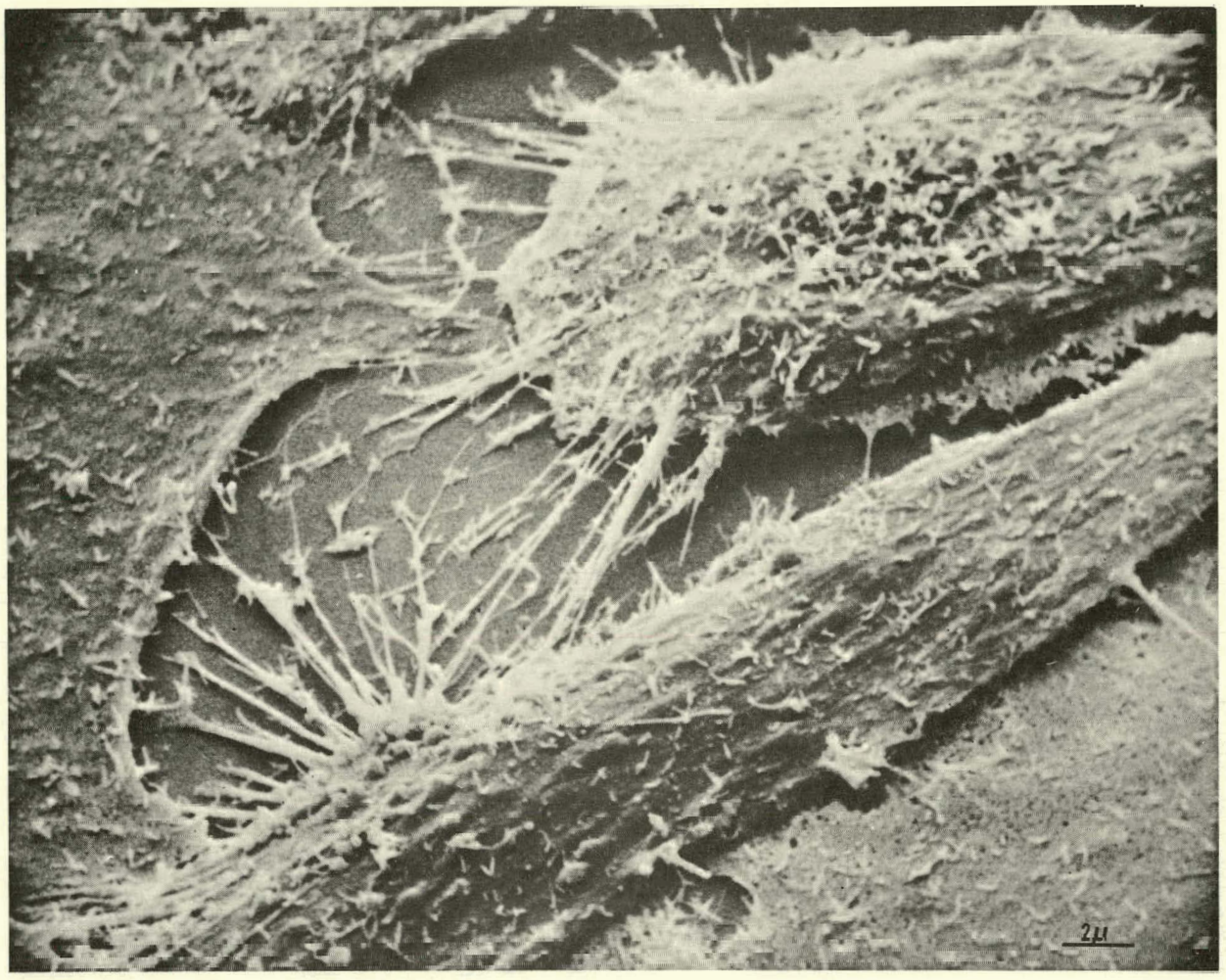


FIG. 5.--Scanning electron micrograph of flattened SaOS osteosarcoma cells with the finely particulate spicules of fast blue BB salt deposited lightly over the cell's surface and along the filopodia extensions.

Automatic GEMSAEC Fast Analyzer

Only CCL5 (HeLa) and SaOS gave readings with the GEMSAEC analyzer which were significantly above background, and their readings were so high that they required 1:5 or 1:10 dilutions to allow quantitation. The background was high because of the presence of 10% FBS in the media which has its own expected alkaline phosphatase activity. The cell lines (TE 85 and AR 177), which had a much smaller number of positively staining cells in the slide technique, could not be distinguished from the background.

When 2 ml samples were heat inactivated at 56°C for 15 minutes and run in parallel with uninactivated samples on the GEMSAEC, the reading for

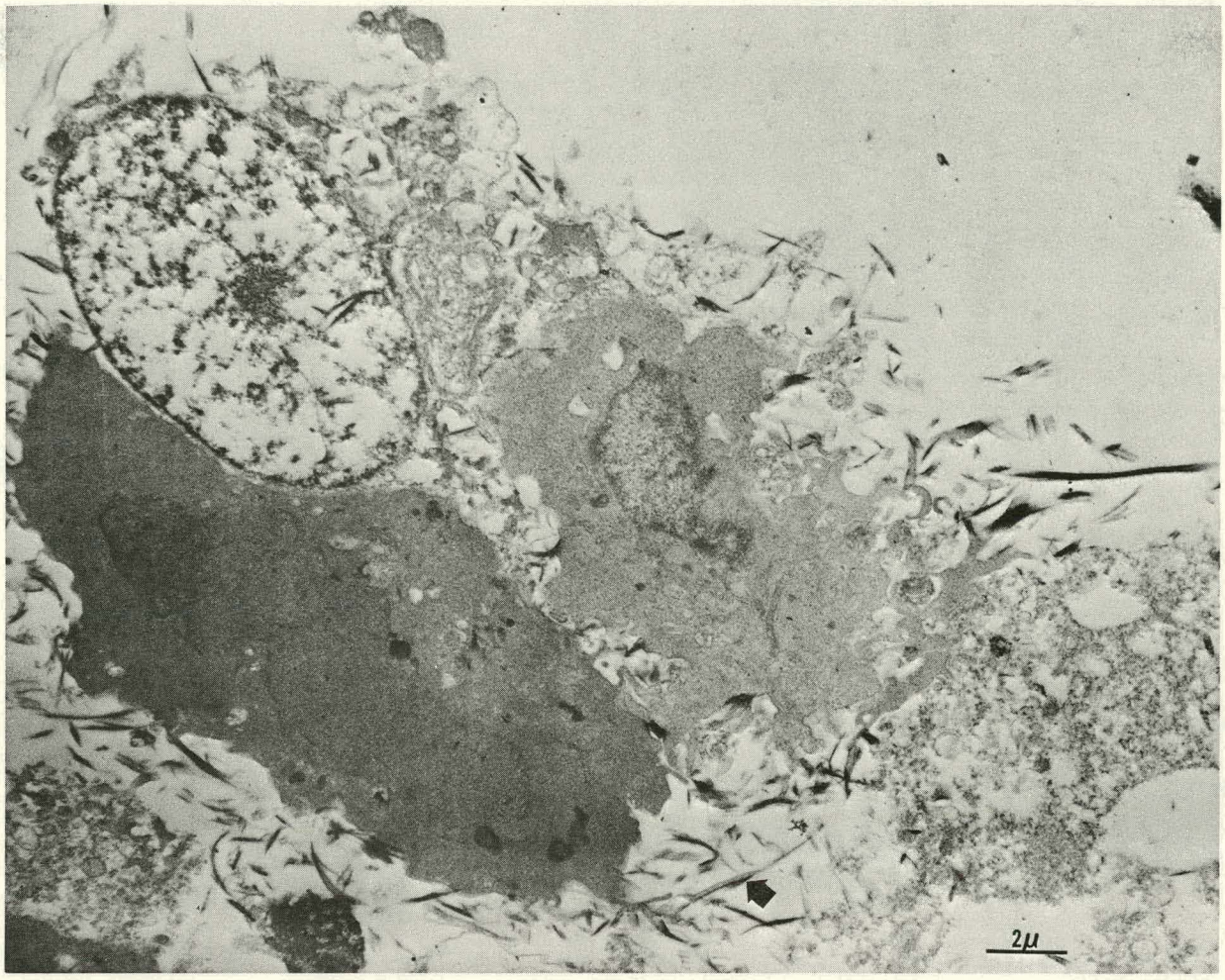


FIG. 6.--Transmission electron microscope picture of SaOS osteosarcoma cells, showing the dark spicules of fast violet B projecting from the exposed surface of each cell's plasma membrane.

the HeLa cells showed no change in activity, whereas the osteosarcoma line (SaOS) showed more than a 70% reduction in activity after heat treatment. This was to be expected since the bone isoenzyme has been shown by others to lose approximately 80% of its activity under these conditions.[5]

## Discussion

Four different techniques have been described for the detection, localization, and quantitation of alkaline phosphatase in order to make a positive identification of osteosarcoma cells in culture.


FIG. 7.--Scanning electron microscope picture of the negative control for osteosarcoma cell line SaOS, showing only blebbing and disorganized criss-crossing characteristic of active malignant cells, but no salt deposits. These cells were incubated without substrate in the alkaline phosphatase staining mixture.

Table 2 shows the advantages and disadvantages of the four different methods with regard to their ease of handling, specificity, and quantitation. From these tests, five of the eight cell lines studied, which were originally derived from osteosarcomas, appear to be suitable for futher immunological work involving bone tumor antigens. None of the cell lines was found to be contaminated with HeLa as determined by the heat sensitive test.

Table 2. Advantages and Disadvantages of Different Techniques for Measurement of Alkaline Phosphatase

| Technique | Advantages | Disadvantages |
|---|---|---|
| Light microscope | Fast, easy to prepare and view samples. Can view individual cells for their reactivity; hence, more sensitive to lower levels of enzyme activity. The light microscope is the only instrument necessary. Should facilitate cloning of cells of interest. | Qualitative results rather than quantitative. Cannot differentiate all isoenzymes reliably. The stain precipitates out after several days and fades upon standing. |
| Scanning electron microscope | Permits the visualization of the localized enzyme activity in three dimensions on cell surfaces with better resolution at higher magnification than available with the light microscope. | Cannot detect sites of activity within the cell. Loss of azo dye during processing. Elaborate equipment necessary. |
| Transmission electron microscope | Permits visualization of active sites within the cell with better resolution at higher magnification than either the light microscope or scanning microscope. | Loss of azo dye during processing. More time consuming than any of the other techniques. Elaborate equipment necessary. |
| Automatic GEMSAEC fast analyzer | Provides a quantitative measure of the enzyme activity, permitting the identification of isoenzymes from different cell types. Requires only small sample volume. Preservation of cells not necessary. Cellular localization of enzymes not involved in interpretation. | Elaborate equipment necessary. Insensitive compared to other techniques as used here. Could probably be made more sensitive by (1) using less FBS, (2) increasing cell number, and (3) concentrating the enzyme, using more cells in less medium. |

Of all of the techniques tested for the identification of osteosarcoma cells in culture using the alkaline phosphatase enzyme, the light microscope using the fast violet B salt appeared to be most sensitive and easiest to use. This technique will be invaluable to us in screening out cell lines which have lost at least some, or all, of the characteristics of the original tumor cells.

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# $^{226}$Ra AND CALCIUM IN THE HUMAN EYE

R. B. Holtzman and J. Y. Sha

The left eye from each of two CHR cases, 01-144 (body burden 690 nCi) and 01-017 (body burden 1210 nCi) was analyzed for $^{226}$Ra and calcium. The total amounts in the eye were 1.80 pCi of $^{226}$Ra and 2.3 mg of Ca in case 01-144, and 5.4 pCi of $^{226}$Ra and 14.2 mg of calcium in case 01-017. For the latter case the eye was dissected and showed the highest concentrations of activity (on a wet basis) in the choroid, 3.8 pCi/g, sclera 3.4 pCi/g and iris 2.9 pCi/g. The radium content of the eye was $2.7 \times 10^{-4}$% to $4.7 \times 10^{-4}$% of the total body content at 50 to 55 yr after first exposure. The $^{226}$Ra/Ca ratios in the whole eye were 1/3 to 1/4 those in the whole body, but that for the choroid from the dissected eye was identical to that of the whole body.

Although $^{226}$Ra is retained principally in the skeleton, it has been shown to deposit significantly in the eye of dogs injected with $^{226}$Ra.[1-3] The dose rates to parts of the canine eye were estimated to be 10 to 100 times those to the skeleton.[3] Various degenerative effects, such as tumors, were noted in the eye. However, these changes have not been observed in humans with high exposure to radium, such as the dial painters and iatrogenic $^{226}$Ra cases.

The high radium concentrations in dogs appear to be associated with melanin and melanocytes and, more specifically, take place in the tapetum lucidum, a specialized tissue between the choroid and the retina (see Figure 1). The absence of ocular effects in man is probably due to the absence of this tissue in the human eye.

The bovine eye has also been shown to accumulate stable barium in the choroid[4] to a much greater extent than does the human eye.[5] Hunt[6] demonstrated the accumulation of naturally-occurring $^{210}$Po, $^{226}$Ra, and $^{228}$Th in the choroid, particularly in cattle. The concentrations of $^{210}$Po were greater than those in bone by a factor of four or more, while the $^{226}$Ra concentrations in choroid were comparable to those in bone. In the eye of human subjects with normal environmental exposure, Hunt also found $^{210}$Po

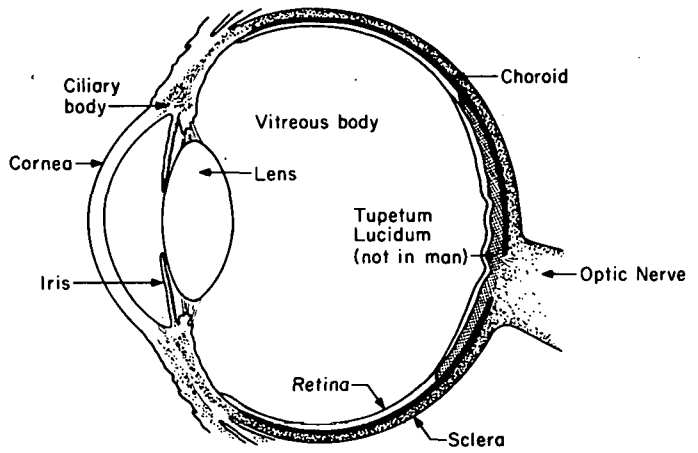


FIG. 1.--Structure of the dog eye.

and $^{226}$Ra concentrations in the choroid comparable to or greater than the respective concentrations in bone.

In order to further compare human and animal data, preliminary results are presented on the $^{226}$Ra levels in eyes, taken at autopsy, of two persons with high body burdens of this nuclide. Case 01-017, a 94-yr old woman, who died in 1976, had drunk Radithor for 3 yr after 1926. Her body content in 1971 was 1210 nCi (1160 nCi at death). Case 01-144, a 76-yr old woman, who died in 1973, had ingested radium for about 6 months in 1922. Her body burden in 1971 was 690 nCi (675 nCi at death).

The entire left eye of case 01-144 was analyzed. The $^{226}$Ra was determined by the radon emanation method of Lucas[7] after dissolution of the sample in a quartz vessel by wet ashing in nitric and perchloric acids. The calcium content was determined by atomic absorption spectrophotometry.[8]

The left eye of case 01-017 was dissected into eight portions—cornea, sclera, lens, vitreous humor, iris, ciliary body, choroid, and retina, and the $^{226}$Ra and calcium content were determined for each portion. A blank sample of the ethanol used to preserve the samples (case 01-017) showed negligible concentrations of $^{226}$Ra (0.00 ± 0.01 pCi/g) and calcium (-0.7 ± 0.1 μg/g). A formalin blank (case 01-144) had very low levels of $^{226}$Ra (0.013 ± 0.003 pCi/g) and calcium (2 ± 0.2 μg/g). Results of the analyses for $^{226}$Ra and calcium in the samples are shown in Table 1.

The eyes may be compared by the total amounts. That of case 01-144 contained only 5.01 mg calcium, compared to the sum of the individual parts

Table 1. Concentrations of $^{226}Ra$ and Calcium in the Human Eye

| Case No. (Body Burden, nCi) | Sample | Wet wt., g | $^{226}Ra$ concentration, pCi/g wet | Total $^{226}Ra$, pCi | Ca concentration, mg/g wet | Total Ca, mg | $^{226}Ra$/Ca ratio, pCi/mg |
|---|---|---|---|---|---|---|---|
| 01-144 (690) | Whole eye | 5.89 | 0.306 ± 0.005 | 1.80 ± 0.03 | 0.85 ± 0.012 | 5.01 ± 0.07 | 0.36 ± 0.01 |
| 01-017 (1210) | Cornea | 0.074 | 0.29 ± 0.12 | 0.020 ± 0.009 | 0.81 ± 0.54 | 0.06 ± 0.04 | 0.36 ± 0.28 |
| | Sclera | 1.385 | 3.42 ± 0.09 | 4.74 ± 0.12 | 9.44 ± 0.13 | 13.1 ± 0.2 | 0.36 ± 0.01 |
| | Lens | 0.283 | 0.05 ± 0.03 | 0.014 ± .008 | 0.42 ± 0.10 | 0.12 ± 0.03 | 0.12 ± 0.08 |
| | Vitreous humor | 4.076 | -0.0006 ± 0.003 | 0 | 0.070 ± 0.007 | 0.28 ± 0.03 | 0.0 |
| | Iris | 0.035 | 2.94 ± 0.44 | 0.103 ± 0.015 | -0.04 ± 0.80 | 0 | >1 |
| | Ciliary body | 0.122 | 0.07 ± 0.08 | 0.01 ± 0.01 | 0.25 ± 0.23 | 0.30 ± 0.03 | 0.28 ± 0.41 |
| | Choroid | 0.139 | 3.83 ± 0.13 | 0.53 ± 0.02 | 2.36 ± 0.21 | 0.33 ± 0.03 | 1.62 ± 0.15 |
| | Retina | 0.164 | 0.09 ± 0.05 | 0.015 ± 0.008 | -0.04 ± 0.17 | 0 | (?) |
| | Total | 6.278 | | 5.43 ± 0.12 | | 14.16 ± 0.19 | |
| | Whole eye | | 0.86 ± 0.02 | | 2.26 ± 0.03 | | 0.38 ± 0.01 |

for case 01-017 of 14.2 mg. The higher values in the latter case may be due to more calcification in this subject, who was 18 years older. She also had a larger fraction of the body content of $^{226}Ra$ in the eye than did case 01-144 ($4.7 \times 10^{-4}$% vs. $2.6 \times 10^{-4}$%). The Ra/Ca ratios of their eyes were essentially identical.

The greatest concentrations of $^{226}Ra$ were in the choroid, sclera, and iris, although the latter tissue may be less important because of its smaller size and thus much lower total activity. The largest amount was in the sclera, which contained nine times as much as the choroid, although the concentrations were quite similar.

The Ra/Ca ratios for the ciliary body and vitreous humor are indeterminate, but are very low, with little radium but significant levels of calcium.

The sclera has a Ra/Ca ratio of about 0.4 pCi/mg. The radium was more concentrated relative to calcium in the choroid, with a ratio of 1.6 pCi/mg, and even more so in the iris, where the radium level was significant, but the calcium content was too low to be determined. Finally, the $^{226}$Ra/Ca ratios in the eye of about 0.4 pCi/mg appear to be lower than those of the whole body, which, if we assume the total calcium content to be 750 g, are about 0.96 and 1.6 pCi/mg for cases 01-144 and 01-017, respectively.

It should be noted that the fractions of the $^{226}$Ra body content in the eyes of these subjects ($4.7 \times 10^{-4}$ and $2.6 \times 10^{-4}$%) are less than 1% of those observed in dogs (at times shorter by two orders of magnitude) by Taylor et al.[9] They obtained an extrapolated value of 0.071% of the initial dose at time of injection, while Fisher et al.[3] observed 0.054% of the body burden at 182 days after the last of eight injections.

It is difficult to compare our results with those for the dogs because of the presence in that species of the tapetum lucidum, which has a much higher specific activity than do other tissues. The dog choroid,[3] which is adjacent to, and may include some of the tapetum activity, had about 20 times the activity of the combined sclera, retina, and cornea. On the other hand, the human eye showed approximately equal specific activities in the choroid and sclera.

The similarities of the Ra/Ca ratios in the human choroid with those in bone (whole body), indicate that the dose rate to the choroid may be similar to that to the skeleton. In addition, other tissues overlying the choroid, such as the retina, may receive a similar dose, even though it contains little activity itself. Little damage has been seen in the eyes of the dial painters and other people containing high levels of radium, and these data substantiate the observation that the human eye may not be very sensitive to alpha radiation dose levels which cause damage to the skeleton.

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# PRECISION, ACCURACY, AND BLANK VALUES IN THE DETERMINATION OF $^{226}Ra$ BY THE RADON EMANATION METHOD

R. B. Holtzman and J. Y. Sha

The precision of the radon emanation system used in the determination of radium was 2.7% with a National Bureau of Standards radon emanation standard of 400 pCi and about 3.5% with a 10 pCi standard. The mean values of results of 12 or more measurements on each of these standards were within 0.5% of the NBS values. "System" blanks (air blank only) were 0.008 ± 0.006 (S.D.) pCi for System A and 0.006 ± 0.006 (S.D.) pCi for System B. For reagent blanks the mean was 0.015 ± 0.004 (S.D.) pCi. The errors of measurement in replicate sample measurements were consistent with those of the NBS standard samples.

The precision and accuracy of the radon emanation method used for the determination of $^{226}Ra$ in our laboratory were estimated from measurements on standard samples. Precision was further estimated from replicate measurements on test samples. Blank values for the method, due to residual $^{226}Ra$ in both the system and in the reagents, were also estimated to correct observed values of low-level samples for the $^{226}Ra$ content of the reagents of the system.

The system has been described by Lucas[1] and is similar to that given in more detail by Nelson and Rust.[2] The sample in solution in a flask is first de-emanated by bubbling radon-free air through the flask to remove residual radon. After a known time (about one-half period of $^{222}Rn$) to allow the radon to grow in, the flask is again de-emanated for about 20 min with radon-free air, and the radon is collected in a charcoal trap cooled to about -78°C with a mixture of dry ice and Freon.

After evacuation of the trap to remove air, it is heated to about 500°C on the transfer system to desorb the radon from the charcoal. A small amount of helium gas to carry the $^{222}Rn$ is added to the system and the gases are pumped by a Sigma transfer pump into a ZnS phosphor-coated Lucas counting bottle. The trap is flushed with helium four additional times to insure almost complete recovery (99.5%) and reproducible transfer of the radon to the bottle.

The residual radon is probably dissolved in the rubber tubing in the transfer system. The radon in the bottle is then determined by counting on a photomultiplier tube the scintillations from the interaction of the phosphor and the alpha particles produced by the decay of the radon and its daughter products. The efficiencies of the bottles are 5.32 counts $(\text{min} \cdot \text{pCi})^{-1}$, and the usual background is about 0.070 counts $\text{min}^{-1}$, which gradually rises as the long-lived daughters of $^{222}Rn$, $^{210}Pb$, and its alpha-emitting daughter, $^{210}Po$, accumulate in the bottle with usage. The amounts of $^{222}Rn$ and of $^{226}Ra$ may then be calculated from the Bateman equations and the various time factors, growth time of the radon in the sample, counting time, etc.

The standard samples were obtained from the National Bureau of Standards in 1974. The lower-level standard (10 pCi) (our laboratory number 97-STD-006) was "Standard No. 4951, Radium Standard (for Radon Analysis), Radium-226, S. S. No. 795943." It contained $1.001 \times 10^{-11}$ g $^{226}Ra$ as of November 1956 in 100 ml of carrier solution consisting of 0.2% $BaCl_2 \cdot 2H_2O$ by weight in a 5% solution of HCl by weight.

The higher level standard was similar, "Standard Reference Material 4950-B, Radium-226 Standard for Radon Analysis" containing $8.06_9 \times 10^{-10}$ g $^{226}Ra$ as of March, 1968 in 20.509 ± 0.012 g of solution. This standard solution was divided into two parts by weight, 10.232 g in one flask (97-STD-003) and 10.226 g in a second flask (97-STD-004). The volumes of all three standards were brought to 250 ml with distilled water and stored in the deemanation flasks. For the higher level standard, the uncertainty is given as $1.0_0$% at the 99% confidence level. For the 10 pCi standard, the errors are not given directly on the certificate itself, but are listed as 0.1% for uncertainties in the 1957 primary $^{226}Ra$ standard, 0.1% for the comparison between sample and standard, and 0.1% for dilution. The sum (the method for propagation of errors used by the NBS) is then 0.3% (S.D.) or about 0.8% (at the 99% confidence level of 2.585 S.D.). The smaller error on the latter sample may be due to its earlier origin, when the NBS may have been less conservative.

Our best estimates of the values, based on the NBS values and corrected for radioactive decay to January 1976 (mean time of the study period), are 9.90 and 401.3 pCi for the smaller and larger standards (97-STD-006 and 97-STD-003), respectively.

During the period June 1974 through May 1977, 12 determinations of the 10 pCi standard gave a mean value of 9.96 ± 0.35 (S.D.) pCi and 14 measurements with the 400 pCi standard gave a mean of 403.4 ± 11.0 (S.D.) pCi, as detailed in Table 1. Thus, these mean values are only about 0.5% higher than the listed NBS values, but well within the uncertainties of the NBS standardization, and of our measurements.

Table 1. Measurements of $^{226}Ra$ in NBS Standard Samples

| Run No. | Standard 1, pCi | Standard 2, pCi |
|---|---|---|
| 1 | 9.78 ± 2% | 402.9 ± 1.5% |
| 2 | 10.01 | 408.1 |
| 3 | 9.74 | 396.0 |
| 4 | 9.93 | 402.3 |
| 5 | 9.42 | 380.3 |
| 6 | 10.02 | 410.7 |
| 7 | 10.64 | 414.0 |
| 8 | 10.27 | 401.8 |
| 9 | 9.72 | 397.1 |
| 10 | 10.44 | 399.4 |
| 11 | 9.53 | 421.0 |
| 12 | 10.07 | 424.1 |
| 13 | | 395.7 |
| 14 | | 396.4 |
| Mean ± S.D. | 9.96 ± 0.35 | 403.4 ± 10.97 |
| ± S.E. | ± 0.092 | ± 3.02 |
| NBS Standard Value (Mean 1974-1977) | 9.90 ± 1.0 | 401.3 ± 4.0 |

It appears from these data that the precision of a single measurement (standard deviation) is 2.7 to 3.5%. The higher level of uncertainty was obtained with the lower activity standard and is due, in part, to poorer counting statistics. The errors in these measurements are due to such causes as variable losses during emanation and transfer, and variability in counting-bottle efficiency, the radon not necessarily being collected in the same counting bottle each time.

A group of blanks was also analyzed for $^{226}Ra$ in order to estimate corrections to be applied to observed sample values. "System" blanks were measured, in which air was passed through the de-emanation system, but the

Table 2. Measurements of $^{226}Ra$ in System and Reagent Blanks

| System Blanks | | | Reagent Blanks | |
|---|---|---|---|---|
| Run No. | System A, pCi ± S.D. | System B, pCi ± S.D. | Sample No. | pCi ± S.D. ± S.E. (n)* |
| 1 | 0.008 ± 0.005 | -0.005 ± 0.005 | 1 | 0.019 ± 0.015 ± 0.006 (7) |
| 2 | 0.016 | 0.008 | | |
| 3 | 0.005 | 0.008 | 2 | 0.008 ± 0.010 ± 0.005 (4) |
| 4 | 0.011 | 0.002 | 3 | 0.018 ± 0.007 ± 0.003 (5) |
| 5 | 0.008 | 0.007 | | |
| 6 | 0.004 | 0.018 | 4 | 0.015 ± 0.006 ± 0.003 (5) |
| 7 | 0.003 | 0.011 | 5 | 0.012 ± 0.004 ± 0.002 (5) |
| 8 | 0.016 | 0.001 | | |
| 9 | 0.006 | 0.011 | 6 | 0.018 ± 0.007 ± 0.0035 (4) |
| 10 | 0.015 | -0.004 | 7 | 0.0098 ± 0.0083 ± 0.004 (5) |
| 11 | 0.013 | 0.012 | | |
| 12 | 0.013 | 0.007 | 8 | 0.017 ± 0.008 ± 0.004 (5) |
| 13 | 0.0055 | 0.008 | | |
| 14 | 0.003 | 0.006 | | |
| 15 | 0.002 | 0.014 | | |
| 16 | -0.003 | 0.009 | | |
| Mean ± S.D. | 0.0079 ± 0.0057 | 0.0057 ± 0.0061 | | 0.0146 ± 0.0042 |
| S.E. | ± 0.0014 | ± 0.0015 | | ± 0.0015(8) |

*n is the number of analyses for each sample.

sample flask was by-passed. Measurements were made on two such systems, A and B. The results for 16 determinations on each are given in Table 2. The mean values were 0.008 ± 0.006 pCi (± 1 S.D., S.E. = ± 0.0015) for System A and 0.006 ± 0.006 pCi (± 1 S.D., S.E. = ± 0.0015) for System B.

The reagent blanks, numbers 1 to 6, were 300 ml of distilled water with 10 to 20 ml of HCl or $HNO_3$ added. Sample Blank No. 7 was a reagent blank made with concentrated acids (500 ml $HNO_3$, 50 ml HCl, and 20 ml $HClO_4$) in 250 ml $H_2O$, while No. 8 consisted of 50, 25, 10, and 250 ml of the respective reagents. These were evaporated to near dryness to remove most of the acids and brought to 300 ml with water. There appear to be no significant differences among the various blanks, so that they may be considered together. The mean

Table 3. Precision of Measurements on Biological Samples

| Sample No. and Type | Concentration ± S.D. obs., pCi | Variance Ratio, F |
|---|---|---|
| 03-424-040 | 0.019 ± 0.004 | |
| Red Blood Cells | 0.009 ± 0.004 | |
| (wash) | 0.020 ± 0.004 | |
| | 0.016 ± .0035 | 2.3 |
| 03-426-020A | 0.002 ± 0.003 | |
| Red Blood Cells | 0.019 ± 0.005 | |
| | 0.032 ± 0.006 | |
| | 0.017 ± 0.012 | |
| | 0.011 ± 0.007 | 8.2 |
| 03-459-020A | 0.043 ± 0.005 | |
| Plasma | 0.061 ± 0.006 | |
| | 0.065 ± 0.009 | |
| | 0.053 ± 0.007 | 3.6 |
| 05-165-Q81 | 1.32 ± 0.04 | |
| Bone | 1.34 ± 0.06 | |
| | 1.33 ± 0.01 | 0.1 |
| 03-528-010 | 12.41 ± 0.15 | |
| Bone | 12.63 ± 0.16 | |
| | 13.32 ± 0.24 | |
| | 12.65 ± 0.19 | 3.6 |
| 01-43-K5C2A | 48.74 ± 0.57 | |
| Bone | 46.24 ± 0.71 | |
| | 47.93 ± 0.79 | |
| | 47.80 ± 0.67 | 3.0 |
| 01-635-K54A | 1316.0 ± 22.4 | |
| Bone | 1358.4 ± 15.9 | |
| | 1344 ± 20.0 | 2.4 |

value is thus 0.015 ± 0.004 (±1 S.D., S.E. = ±0.0015) pCi, the value presently used in our calculations.

Finally, Table 3 gives data from seven biological samples chosen at random to indicate the reproducibility of replicate measurements at different levels of activity. The F value is the ratio of the external (observed) variance to the predicted variance (from counting statistics and a 1% systematic error). While the number of replicate measurements is too small to obtain meaningful values of F, the fact that these F values are not grossly different from unity indicates a good reproducibility, comparable to that seen in the NBS standards.

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(04) E

# METABOLIC BALANCES OF $^{210}$Pb AND $^{210}$Po AT NATURAL LEVELS*

Herta Spencer,† Richard B. Holtzman, Lois Kramer,† and F. H. Ilcewicz**

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Metabolic balances of $^{210}$Po and $^{210}$Pb were determined under strictly controlled dietary conditions in adult males. The intakes of the two nuclides were due to the dietary contents of these radioisotopes, inhalation from the atmosphere, and smoking of cigarettes. No additional radioisotope was given. The mean dietary intake of $^{210}$Pb was 1.25 pCi/day and of $^{210}$Po, 1.63 pCi/day. The major pathway of excretion of both nuclides is via the gastrointestinal tract; the urinary excretion is much lower. The total excretions of $^{210}$Pb and $^{210}$Po were greater than the dietary intake and the overall balances were -0.28 and -0.16 pCi/day for the two nuclides, respectively, during a low calcium intake. The $^{210}$Pb balances did not change significantly when the calcium intake was increased 7- to 10-fold except for one patient in whom the balance became more negative. The $^{210}$Po balance was more negative during calcium intakes of 800 and 2200 mg than during a low calcium intake of 200 mg/day. The urinary and fecal excretions of the two radionuclides were not affected by the intake of sodium fluoride, while the diuretic compound, Hydrodiuril, appeared to decrease the fecal $^{210}$Pb excretion.

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(OK) E

# VARIABILITY OF EXCRETION RATES OF $^{210}$Pb AND $^{210}$Po OF HUMANS AT ENVIRONMENTAL LEVELS*

R. B. Holtzman, H. Spencer,† F. H. Ilcewicz,** and L. Kramer†

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Variability of the excretion rates of the nuclides $^{210}$Pb and $^{210}$Po at natural levels was studied in a group of samples collected from men maintained under the carefully controlled conditions of a metabolic ward. They consumed only the standard diet of the ward in which they had been resident for at least several months prior to this study. The mean urinary rates were about 0.1 to 0.5 pCi/day for both $^{210}$Pb and $^{210}$Po, while fecal rates ranged from 1 to 2.7 pCi/day for the two nuclides. For urinary $^{210}$Pb the coefficients of variation (ratio of standard deviation to mean) for three subjects ranged from 19 to 45% for eight continuous 24-hr samples compared to 11 to 13% for subsequently collected multiday samples (4 to 9 days each) for each subject. However, the standard errors of the means for the one day collections were about equal to the standard deviations of the pooled samples. Similar variability was noted for the $^{210}$Po data. Six day fecal collections from these time periods exhibited higher variabilities than did the urine, from about 12% to 50% for each of the nuclides. Multiday collections for 12 subjects showed mean coefficients of variation of about 16% for $^{210}$Pb and 13% for the $^{210}$Po for urine and 21 and 25%, respectively, in fecal collections. Since dietary intake was maintained fairly constant, excreta collections were carefully controlled, and the analytical precision was about 5%, these variabilities appear to be due to biological variations and are characteristic of the individuals studied. Some possible causes of these effects are discussed.

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# DETECTION OF RADIUM IN BURIED REMAINS

H. A. May

Methods are under investigation to measure radioactivity at the fractional microcurie level in the skeletal remains of persons suspected of long-term radium exposure without moving the bones from their burial site. As practically all soils contain radium, the background level will be high and, possibly, spatially variable, limiting the detection sensitivity. Some experiments and calculations to estimate the capability of simple, transportable equipment are described.

## Introduction

Determination of $^{226}Ra$ in skeletal remains of former radium dial painters forms an important part of the ongoing CHR-ANL studies, because much of the population died before large-scale radium studies were started. However, it is not always possible to obtain permission to transfer the remains from the burial site to the Laboratory. In such circumstances, radioactivity measurements without disturbing the remains might be permitted. The work reported here was undertaken to determine the lower limits of detection of radium in remains at the gravesite, utilizing transportable counting equipment.

## Methods

Size of the detector employed is determined by the conflicting requirements of sensitivity and reasonable weight—not to exceed about 70 kg if mechanical means of handling are to be avoided. A two-piece lead shield was fabricated as shown in Figure 1. The shield was 23 cm long and the outside diameter 20 cm, with 5 cm thick walls and stainless steel exposed surfaces. The 10 × 10 cm Harshaw NaI(Tl) crystal detector rested upon an inner ledge, so that the detector front face was recessed 4 cm. The total weight of the detector with the shield was 66 kg (145 lbs). The counting rates from natural background obtained with the shield resting on the ground and at depths of 30.5 cm and 1 meter in a 23 cm diameter hole are shown in Table 1. The counting rates when surrounded by soil are roughly 15% higher than the corresponding

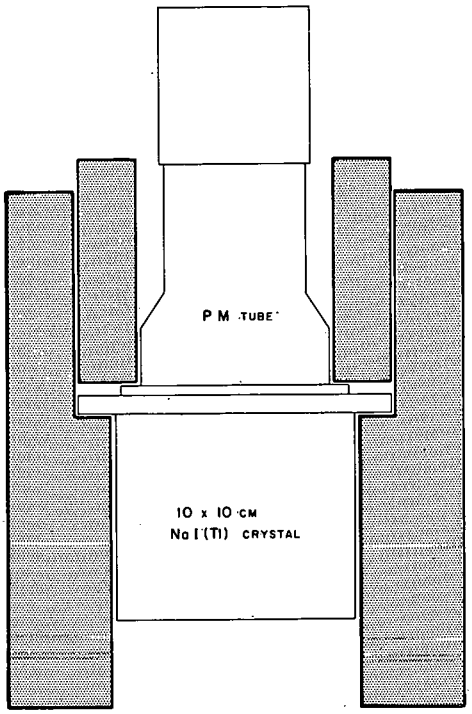


FIG. 1.--Crystal detector and the lead shielding (shaded area).
(ANL Neg. 149-77-326 Rev. 1)

Table 1. Background Counting Rates ($min^{-1}$) in Shield at Various Locations

| Energy band, MeV | On surface | 30.5 cm below surface | 1 meter below surface |
|---|---|---|---|
| 0.3 – 0.4 | 690 | 803 | 785 |
| 0.55 – 0.67 | 425 | 468 | 462 |
| 1.0 – 1.25 | 343 | 413 | 401 |
| 1.35 – 1.55 ($^{40}K$) | 321 | 392 | 370 |
| 1.55 – 1.9 | 121 | 131 | 125 |

surface rates, resulting primarily from the ubiquitous radium and thorium in soil. Additional shielding of the sides would afford no significant reduction in detection capability.

As a first approximation to the intended source, a sealed radium source was placed at various depths in undisturbed soil. A one inch diameter hole was drilled at a 45° angle in the clay subsoil near our laboratory building and a length of plastic pipe inserted. When the source was lowered into the pipe, the vertical distance from the detector at the surface could be calculated

readily up to a maximum depth of 1.5 meters. Counting rate data were collected with a 400 channel analyzer and a 15 μCi source at various depths to 120 cm. Because of the predominantly Compton scattering mode of interaction, the radium peaks were rapidly suppressed so that at a depth of 60 cm, only the barest suggestion of a peak at 1.76 MeV could be discerned in the gamma-ray spectrum (see Figure 2). Attenuation in this energy region was found to fit the theoretical $\frac{e^{-\mu x}}{x^2}$ relationship very closely. The observed net counting rates per microcurie of radium (source in equilibrium) for various energy bands at depths of 30.5, 45.8, and 61 cm are tabulated in Table 2. These figures

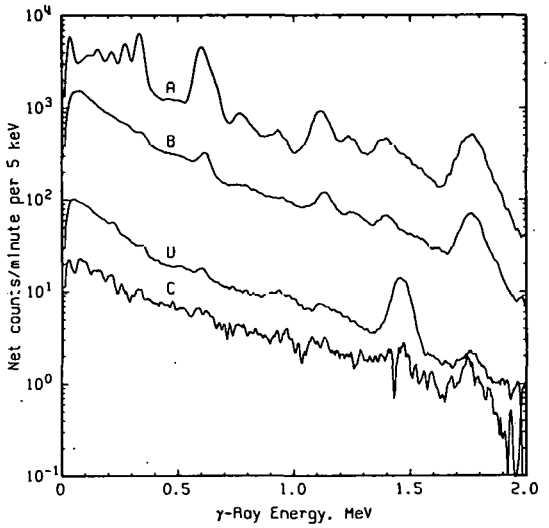


FIG. 2.--Comparison of spectra from $^{226}Ra$ at selected depths in soil, and a typical background, with detector on the surface. A, 15 μCi at surface; B, beneath 30.5 cm soil; C, beneath 61.0 cm soil; D, background.

Table 2. Net Counting Rates ($min^{-1}$) per Microcurie of $^{226}Ra$ (Point Source) Versus Depth in Soil of Source

| Energy band, MeV | 30.5 cm | 45.8 cm | 61 cm |
|---|---|---|---|
| 0.3 – 0.4 | 773 | 99.6 | 23.5 |
| 0.55 – 0.67 | 467 | 69.3 | 9.75 |
| 1.0 – 1.25 | 295 | 48 | 7.6 |
| 1.55 – 1.9 | 176 | 23.5 | 4.35 |

might be combined with appropriate backgrounds to calculate the limits of radium detectability at various depths, based upon the usual $3\sigma$ convention. Such analysis is misleading, however, since uncertainties due to counting statistics are relatively minor compared with the uncertainties arising from lack of accurate knowledge of bone position and distribution. Thus, it would appear to be safe to say that skeletal remains containing a total of 1 μCi would certainly be detected at a distance of 46 cm, and possibly at somewhat greater depths. Positive identification at the 0.1 μCi level, on the other hand, becomes barely possible at a distance of 30.5 cm.

The response expected from an extended line source distribution, which may be considered as a second approximation to a three-dimensional skeleton, may be calculated by evaluation of the integral

$$Y = \int_{-x}^{+x} \frac{e^{-\mu r}}{r^2}\, dx \quad ,$$

where $r^2 = y^2 + x^2$, y is the perpendicular distance of the detector to the line source at the origin ($x = 0$), and x is the distance from the origin of the active line element dx. The integral was evaluated numerically with a computer program SKELSCAN employing the AMD library subroutine ANC4, an adaptive integration based on the Newton-Coates formalism. Values of the half-integral from $x = 0$ to $x = a$ were calculated at 5 cm intervals, and were normalized to the integral for $x = 92$ cm.* Table 3 presents the results for several reasonable values of y. A suitable value for attenuation coefficient was calculated for a "soil" consisting of 4.4% hydrogen, 56% oxygen, 17% aluminum, and 22.6% silicon.[1] The density of the clay subsoil in the vicinity of the experimental setup was found to be 2.07 $g/cm^3$. The lengths of line segment which would contribute 95% of the total response are shown at the bottom of Table 3.

We conclude that a detector centrally positioned 30 cm (~ 12") above the skeletal remains, responds only to a region some 65 cm (25.6") in diameter,

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*This length of line source corresponds to a "maximum-sized" subject six feet long. The difference in normalizing to an infinitely long source is negligible.

Table 3. Normalized Integral Y as a Function of Spatial Parameters

| a, cm | y, cm 20 | 30 | 40 | 60 |
|---|---|---|---|---|
| 5 | 33.8 | 26.6 | 22.5 | 17.9 |
| 10 | 60.5 | 49.8 | 43.0 | 34.8 |
| 15 | 78.1 | 67.7 | 60.1 | 49.9 |
| 20 | 88.3 | 80.3 | 73.2 | 62.7 |
| 30 | 96.7 | 93.3 | 89.2 | 81.1 |
| 40 | 99. | 97.9 | 96.0 | 91.4 |
| 50 | | 99.3 | 98.6 | 96.4 |
| 26.6 | 95.0 | | | |
| 32.8 | | 95.0 | | |
| 37.7 | | | 95.0 | |
| 46.6 | | | | 95.0 |

Values in the table are $Y_{norm} = 100.Y_a/Y$, i.e., the per cent of count rate contributed by a line segment of length 2a to that of an infinite length. $\mu = 0.1034\ cm^{-1}$ (soil at 1.76 MeV).

or to somewhat less than half of the total bone content. Since exact knowledge of skeletal position is unavailable, it may well be that a test hole will position the detector so near the head (or feet) that even less of the total is effectively counted. These conclusions are for the least attenuated principal gamma ray (1.76 MeV); higher attenuation at lower energies makes detection even more uncertain. For soils containing much larger amounts of radium than that at Argonne (about 2 pCi/g) the limit of detection would be much higher. Also ground water is often encountered with extremely high dissolved radon levels. Hence local conditions may easily reduce detection capability by an order of magnitude.

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# MEASUREMENTS OF RADIOACTIVITY IN FORMER THORIUM WORKERS*

J. Rundo, D. R. Huff, and D. R. Kuchta

In the studies of the possible health effects of occupational exposure to compounds of thorium, and of the metabolism of inhaled thorium, 100 men were selected randomly for physical examination from the morbidity study group of 558 men who had worked at a thorium refinery for one year or longer in occupations involving probable exposure to compounds of thorium. Measurements of radioactivity in vivo have now been made on 40 of the 100. Before these subjects visited the Center for Human Radiobiology, we investigated the radioactive content of six other men who were thought to have been exposed to radioactive dust and aerosols. The presence in these men of members of the thorium decay chain showed that we could expect to find radioactivity in at least some of the 100 subjects. We summarize here our findings for these 46 individuals.

Radioactivity confined to the thorax was determined from gamma-ray spectra accumulated from two 29-cm diameter by 10.8-cm thick crystals of NaI(Tl), one above and one below the chest of the supine subject. The background counting rates of the detectors and the counting efficiency to a standardized source of thorium in a lung phantom were such that the statistical standard error for a 30-min measurement was a little less than ± 100 pCi.

The freely emanating content of $^{224}$Ra was determined by electrostatic collection of the solid decay products ($^{216}$Po and especially 10.6-hr $^{212}$Pb) of exhaled 55-second $^{220}$Rn (thoron). The alpha-particle activity was counted in 4π geometry, and the decay curve was fitted by least squares analysis. For breath sampling times of 50 min, the statistical standard error on the amount of $^{224}$Ra equivalent at the mouth of the subject is commonly less than ± 0.5 pCi. A systematic error of ± 10% due to uncertainty in the

*Summary of part of paper presented at International Meeting on Toxicity of Thorotrast and Other Alpha-Emitting Heavy Elements, Lisbon, Portugal, June 28–July 2, 1977.

calibration of the system and a random error of ±15% due to uncertainty in the constancy of the fraction of emanating $^{224}Ra$ are propagated with the statistical error.

The results of the gamma-ray measurements are summarized in Table 1. For six of the subjects with chest contents of less than 0.2 nCi, the results were statistically significant (content ≥ 2σ), so we may say that significant activity was observed in 21 of the 46 men.

The distribution of the emanating $^{224}Ra$ contents is shown in Figure 1 Of the four cases with less than 1 pCi $^{224}Ra$, one gave a significant result (0.6 ± 0.2 pCi), while the other three gave results which were not significantly different from the mean value for 7 control subjects (0.12 ± 0.10 pCi).

The ratio of emanating $^{224}Ra$ to retained $^{212}Bi$ varied from 0.013 to 0.47; the median value was about 0.05. There was no significant correlation between the ratio and either the time since first employment or the time since mid-employment. If there had been a slow migration of thorium from lung to lymph nodes, a negative correlation might have been expected.

Table 1: Provisional Results of Measurements of Retained $^{212}Bi$, Assumed to be Uniformly Distributed Throughout the Thorax

| Thorax content of $^{212}Bi$, nCi | Number of subjects |
|---|---|
| ≥ 2.0 | 2 |
| 0.2–1.9 | 13 |
| < 0.2 | 31 |

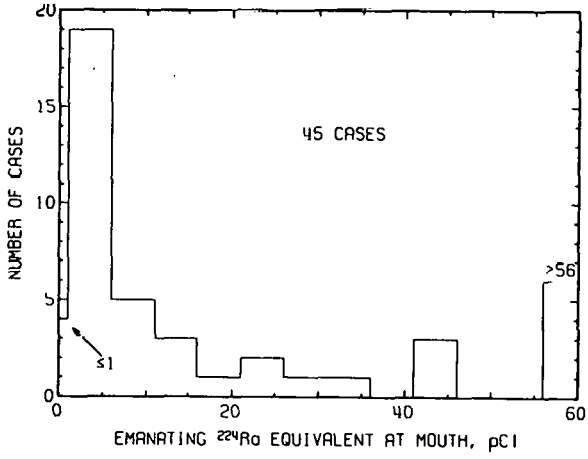


FIG. 1.--Distribution of values of freely emanating $^{224}Ra$ (as at the mouth of the subjects) for 45 cases; the six highest values ranged from 57 pCi to 161 pCi.

# RADIOCHEMICAL METHOD FOR THE DETERMINATION OF $^{228}$Th IN BONE

Robert P. Larsen, Paul J. Meechan,* and Robert D. Oldham

A radiochemical method has been developed for the determination of $^{228}$Th in bone. The limit of detection at the 95% confidence level is about 5 fCi when a 24-hr counting period is used. The method can be used to establish the level of $^{228}$Ra in bone, provided that the $^{228}$Ra and $^{228}$Th are known to be in transient equilibrium. With minor modifications the method could be used to establish whether or not these nuclides are in equilibrium or to determine $^{228}$Ra unequivocally.

An alpha spectrometric-isotope dilution method has been developed for determining the concentration of $^{228}$Th in bone. The bone is ashed, a known amount of $^{230}$Th is added, the ash is dissolved, and the thorium is separated from the inert and other radioactive constituents of the sample. The separated thorium is deposited on a planchet by electroplating, and the planchet is assayed in an alpha spectrometer to determine the $^{228}$Th-to-$^{230}$Th activity ratio. The $^{228}$Th activity in the sample is calculated by multiplying this ratio by the amount of $^{230}$Th added initially. Thorium recovery in this procedure ranges from 70 to 95%.

The procedure for separating the thorium activities from the other constituents of the sample is similar to the one used for the x-ray spectrometric determination of natural thorium in bone.[1] The thorium is separated from phosphate by precipitating about 10% of the calcium as the oxalate; this precipitate carries more than 90% of the thorium. The calcium oxalate is dried, and is converted to calcium carbonate at 600°C. The carbonate is dissolved in strong nitric acid, the solution is passed through a Dowex-1 anion exchange column, and the column is washed with strong nitric acid. This operation separates thorium from calcium and other constituents of the sample that precipitated with the calcium oxalate, because thorium is strongly adsorbed onto

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the anion exchange resin from nitric acid, while the other constituents are not adsorbed. The thorium is eluted from the column with dilute hydrochloric acid, the solution is converted to a sulfate medium, and the thorium is electrodeposited onto a stainless steel planchet.

The factors that limit the sensitivity of this method are primarily the background of the detector, the counting geometry, and the time that can be devoted to the activity measurement. The background of a typical detector in the energy region of interest, 5.35 to 5.43 MeV, is one count per day; the geometry is about 35%. Two blank values obtained by analyzing a synthetic bone-sample solution were not significantly different from the detector background. The average background of 1 count/day corresponds to the counting rate from 2 fCi $^{228}$Th on the planchet, so the limit of detection is about 5 fCi for a 24-hr observation of activity.

The accuracy of the method is limited only by the $^{228}$Th counting statistics. The level of $^{230}$Th activity added to the sample is about one pCi. The only other natural radionuclide having a principal alpha particle whose energy is close to that of the principal alpha particle of $^{228}$Th at 5.43 MeV, is $^{222}$Rn at 5.48 MeV. The presence of $^{222}$Rn would be immediately apparent from the presence in the spectrum of peaks due to the alpha particles from its parent, $^{226}$Ra, and daughters.

The method was tested by analyzing a synthetic bone-sample solution to which known amounts of $^{228}$Th had been added. The concentrations were 730, 73, and 7.3 fCi per gram of calcium phosphate. The values obtained agreed with these concentrations within the statistics of counting.

The method was also tested by analyzing samples of bone that were known to contain $^{228}$Ra and had been analyzed by the deemanation method.[2] The values obtained by the two methods are given in Table 1. Each value is the result of a single analysis.

In comparison with the deemanation method, the principle advantage of this new method is better reliability when the amount of $^{228}$Ra in the sample is less than about 0.2 pCi. Experience with the deemanation method has shown that at this level the blanks are irreproducible, and hence the results

Table 1. Comparison of $^{228}Th$ Values Obtained by Two Different Methods of Analysis (pCi/g ash)

| Deemanation | Radiochemical $^{228}Th$ |
|---|---|
| 6.1 ± 0.3 | 4.8 ± 0.4 |
| 0.49 ± 0.05 | 0.58 ± 0.03 |
| 0.11 ± 0.015 | 0.090 ± 0.008 |

obtained are not reliable.

With a minor modification in the procedure, the method can be used to establish whether or not the $^{228}Ra$ and $^{228}Th$ in the sample were in equilibrium or to determine the $^{228}Ra$ concentration unequivocally. This can be done by precipitating all the calcium as the oxalate rather than 10% of it, collecting and saving all the strong nitric acid that is passed through the anion exchange column, and analyzing this solution for $^{228}Th$ at a subsequent date. (Precipitating only part of the calcium is an operational convenience.) Precipitation of all the calcium ensures complete recovery of the $^{228}Ra$; in strong nitric acid all the $^{228}Ra$ passes through the ion exchange column and all the $^{228}Th$ is adsorbed onto the resin. To analyze the nitric acid solution for $^{228}Ra$, a known amount of $^{230}Th$ would be added after $^{228}Th$ had grown in, and that part of the procedure that follows the dissolution of calcium carbonate would be repeated. The $^{228}Th$ found would be a measure of the $^{228}Ra$ in the original sample of bone. For the analysis of samples where there is serious doubt about the existence of equilibrium, the procedure would include complete precipitation of calcium oxalate, but the $^{230}Th$ would not be added to the initial acid solution of the bone ash, and the steps of the procedure that follow the washing of the anion exchange column with nitric acid after dissolution of the first precipitate of calcium oxalate would be omitted. The initial $^{228}Th$ content of the sample would not be determined.

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# OXIDATION OF Pu(IV) TO Pu(VI) BY CHLORINE—CONSEQUENCES FOR THE MAXIMUM PERMISSIBLE CONCENTRATION OF PLUTONIUM IN DRINKING WATER

R. P. Larsen and R. D. Oldham

It is shown that soluble plutonium is oxidized to the VI state when drinking water is chlorinated. As a result it appears that the present value for the maximum permissible concentration of plutonium in drinking water may be three orders of magnitude too high.

In deriving the value for the maximum permissible concentration of plutonium in drinking water, a value of $3 \times 10^{-5}$ was used for $f_1$, the fraction transferred from the gastrointestinal tract to the blood.[1] The task group that was established in 1965 to review the metabolism of plutonium concurred with this.[2] In so doing the conclusion appears to have been drawn that the value of $2 \times 10^{-2}$ for $f_1$ when plutonium is in the VI state, as reported by Weeks et al.,[3] is erroneous, or that Pu(VI) is rapidly reduced to the IV state in the G.I. tract, or that there is little or no probability that plutonium in drinking water will be in the VI state. As indicated below, none of these conclusions was warranted.

There is no apparent reason to question the data of Weeks et al. for the absorption of Pu(VI). Solutions that had 4, 15, and 100% of the plutonium in the VI state were intragastrically administered to three sets of 12 rats; 6 rats from each set were sacrificed after 4 days and 6 after 80 days, and the liver and skeleton of each rat were analyzed for plutonium. The correlation between the fractional uptake of the administered dose and the fraction of Pu(VI) in the solution used was extremely good.

That the absorption factor for Pu(VI) is much higher than that for Pu(IV) is not surprising. In fact, had the values that Weeks et al. obtained for Pu(VI) been comparable to the value that they and others obtained for Pu(IV) about $10^{-5}$, the only reasonable explanation would have been that Pu(VI) was rapidly reduced to Pu(IV) in the G.I. tract (see below). Np(VI) is readily absorbed from the G.I. tract of the rat ($f_1$ is $2 \times 10^{-2}$),[4] and U(VI) is readily

absorbed from the G.I. tract of man ($f_1$ is 0.1 to 0.3).[5] Pu(VI) is such a close chemical analog of U(VI) that the best estimate of the value of $f_1$ for Pu(VI) in man might well be the value of $f_1$ for U(VI) in man.

The data obtained by Weeks et al. also demonstrated that the reduction of Pu(VI) to Pu(IV) in the G.I. tract is not a rapid reaction. When Pu(VI) was administered, about 2% was found in the skeleton and liver of the rats after 4 days. Had the Pu(VI) been reduced to Pu(IV), their data on the absorption of Pu(IV) shows that only 0.001% would have been found in these tissues. This observation is in agreement with what is known about the rates of reduction of Pu(VI) at low concentrations in vitro; they are very slow reactions.

Since the chlorination of drinking water is standard practice in water treatment systems, the effect of this treatment on the oxidation state of plutonium must be considered. Hamaker has shown that chlorine is capable of oxidizing Pu(IV) to Pu(VI) in neutral media.[6] He found that oxidation to the VI state was complete after 15 min at 80°C in acetate buffered solutions that had a pH of 4.0 to 8.4, were 0.1 M in hypochlorite, and contained "trace" amounts of plutonium in the IV state. Oxidation would be predicted from standard oxidation-reduction potentials. In acidic solution the potentials for the Cl(0)–Cl(-I) and Pu(VI)–Pu(IV) couples are 1.37 and 1.04 V, respectively, while in basic solution they are 0.89 and 0.51 V, respectively. However, these data cannot be used to predict the oxidation of plutonium in water treatment systems because the rate of reaction could be so slow that the fraction of Pu(IV) oxidized to Pu(VI) would be negligible. The concentrations of the reactants in a water treatment system are orders of magnitude lower than they were in Hamaker's experiments, and the temperature is 10 to 20°C, rather than 80°C. Offsetting these factors is the reaction time: in water treatment it is a day or more.

A series of experiments with Chicago drinking water was done in our laboratory. Solutions of Pu(IV) and sodium hypochlorite were successively added to samples of the water, and the solutions were analyzed for Pu(IV) and Pu(VI) immediately and after 24 hr. The plutonium concentration was 5 fCi/ml (a factor of $10^3$ lower than the present MPC), and the chlorine concentrations

were 1 and 10 ppm. (One day is the average elapsed time from initial chlorination to consumption in the Chicago system; one ppm is the average chlorine concentration. In water treatment systems with higher bacterial concentrations in the resource waters, the chlorine concentrations may be as much as 10 ppm.) The solutions were analyzed for Pu(IV) and Pu(VI) by the lanthanum fluoride method.[7] When hydrofluoric acid is added to a dilute acid solution containing milligram amounts of lanthanum, lanthanum fluoride precipitates. Pu(IV) coprecipitates with the lanthanum fluoride, while Pu(VI) remains in the supernatant solution.

From the results given in Table 1, it is clear that the predominant oxidation state of plutonium in drinking water that has been chlorinated is VI. This and the facts that (1) hexavalent actinide ions are readily absorbed from the gastrointestinal tract and (2) the reduction of Pu(VI) to Pu(IV) in the G.I. tract is a very slow reaction, strongly suggest that the present value for the MPC of plutonium in drinking water is three orders of magnitude too high because a larger value of $f_1$ should have been used.

Table 1. Oxidation of Pu(IV) to Pu(VI) by Chlorine in Chicago Drinking Water

| Chlorine conc., ppm | Days | Percent Pu(IV) | Pu(VI) |
|---|---|---|---|
| 1.0 | 0.01 | 98 | 1 |
| 1.0 | 1.0 | 28 | 69 |
| 9.8 | 1.0 | 4 | 92 |

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# AN ALPHA COUNTING CHAMBER FOR USE WITH SURFACE BARRIER DETECTORS*

R. P. Larsen and R. F. Selman†

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An alpha counting chamber has been built and tested that incorporates such desirable features as a method for introducing and positioning the planchets at a high and reproducible geometry, a system for both mounting the detector conveniently and protecting it against contamination and physical damage, and the use of vacuum seals that are completely dependable.

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*Abstract of a paper that has been accepted for publication in Radiochemical and Radioanalytical Letters.

†Central Shops

# THE DETERMINATION OF SKELETAL $^{239}Pu$ BY EXTERNAL COUNTING AT THE SKULL

R. E. Toohey

The feasibility of determining in vivo the amount of $^{239}Pu$ in the skeleton of a contaminated individual has been demonstrated by radioactivity measurements made on the skull of case 40-010. A minimum detectable activity of 10 nCi $^{239}Pu$ (one-fourth the maximum permissible skeletal burden) is indicated, although calibration for measurements in vivo remains a difficult problem.

## Introduction

The suitability of the skull as a site for the determination of "bone-seeking" radionuclides by external counting in vivo has been pointed out by Dolguirev et al.,[1] and also by Cohen et al.[2] Both groups demonstrated the technique for $^{210}Pb$ and $^{241}Am$, and Cohen[2] suggested its use for $^{239}Pu$. The advantages of the skull are that there is little soft tissue overlying the bone; the skull can be nearly surrounded by detectors, which can be shielded from the rest of the body; and the skull seems to be representative of the skeleton, i.e., the concentration of the radionuclide in the skull is approximately equal to the average concentration in the entire skeleton. This has been demonstrated to be true in both animals and humans for $^{241}Am$,[3,4] and in animals for $^{238}Pu$.[5]

The feasibility of this technique for the detection in vivo of $^{239}Pu$ deposited in the skeleton was investigated by radioactivity measurements on the skull of case 40-010. This female subject was injected with 4.9 μg of plutonium as part of an excretion study in 1945 at the age of 18. She succumbed to her pre-existing illnesses in 1947 and her remains were exhumed by the Center for Human Radiobiology in 1974.

## Experimental Methods

The skull was cleaned of soft tissue, with the periosteum left intact. It was immersed in a 7% ethanol solution to retard bacterial growth and allowed

to dry in air. It was then wrapped in a polyethylene bag and placed 10 mm from the face of a 180-mm diameter xenon-filled proportional counter. A 2.5-mm thick layer of tissue-equivalent absorber was interposed to represent the scalp, and the uranium L x rays which follow the α decay of $^{239}Pu$ were counted for 1000 minutes. Several spectra were collected with the skull in different orientations relative to the counter, and a representative spectrum is shown in Figure 1. Approximately 20% of the counts in the energy band 11 to 25 keV are due to $^{240}Pu$ and $^{241}Am$, with the remainder due to $^{239}Pu$.[6]

In order to determine the effective depth at which the plutonium is buried within the skull, a series of spectra was collected from a point source of $^{238}Pu$ covered by successive layers of thinly-sliced cortical beef bone.

The ratio of counts in the $L_\alpha$ peak (11.8–15.4 keV) to those in the $L_\beta$ peak (15.4–19.0 keV) was calculated for each spectrum, and this ratio is plotted in Figure 2 as a function of bone thickness covering the source. The value of the $L_\alpha/L_\beta$ ratio calculated for the spectrum obtained from the skull (Figure 1) is 0.63, and this indicates an effective bone thickness of 0.4 mm by interpolation of the data in Figure 2. This "effective depth" indicates that the detector is sensitive to plutonium buried within the bone matrix, and consequently is not limited to detecting only that plutonium which lies on the outer bone surface.

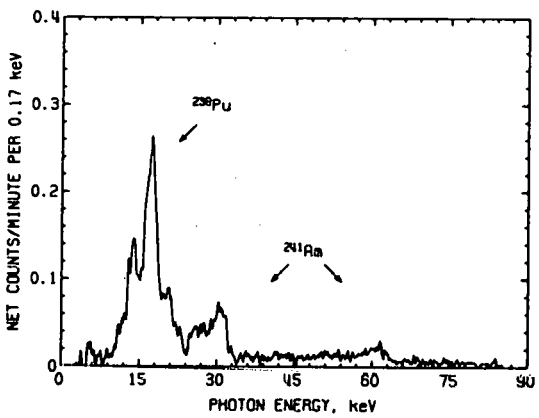


FIG. 1.--The x-ray spectrum obtained from the skull of case 40-010, presented frontally to the counter, with 2.5 mm absorber interposed. The peaks at 26.3, 30.0, and 59.6 keV are due to $^{241}Am$, and the peaks at 13.6, 17.2, and 20.2 keV are due primarily to L x rays emitted following the decay of $^{239}Pu$.
(ANL Neg. 149-77-281)

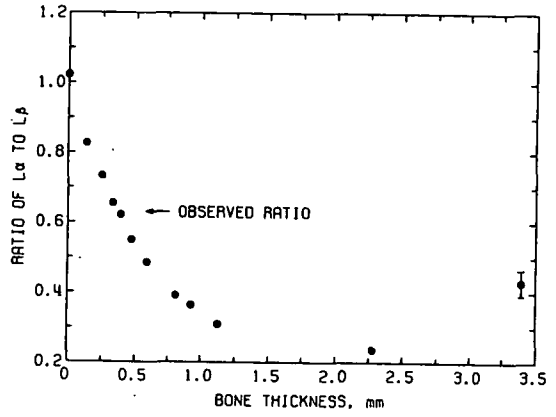


FIG. 2.--The ratio of counts in the $L_\alpha$ peak (11.8–15.4 keV) to those in the $L_\beta$ peak (15.4–19.0 keV) as a function of bone thickness covering a plutonium source. The arrow indicates the value of the $L_\alpha/L_\beta$ ratio observed in the spectrum from the skull. (ANL Neg. 149-77-280)

## Calibration and Discussion

In order to calibrate this method of determining skeletal plutonium by counting at the skull, the total amount of plutonium in the skeleton of case 40-010 must be known. Since radiochemical analysis of the skeleton is not yet complete, this amount must be calculated from the amount injected. By allowing for a small amount excreted before death and assuming 45% retention in the skeleton, Larsen et al.[6] estimated the skeletal burden to be 135 nCi $^{239}$Pu. The net counting rate due to $^{239}$Pu observed from the skull varied with orientation from 9 to 11 cpm. The spectrum in Figure 1, as an example, gave 9.1 cpm. For 135 nCi $^{239}$Pu in the skeleton, this gives a calibration factor of 15 nCi/cpm. A representative background from the skull of a control subject in vivo is 3.3 cpm, so for a 60 min count, the minimum detectable activity (3 $\sigma$ of background) is 10 nCi $^{239}$Pu in the skeleton.

It must be emphasized that this skeleton is highly abnormal. At the time of injection, this subject was suffering from Cushing's syndrome, osteoporosis, nephropathy, and hypertension. Consequently, any calibration based on this skeleton must be considered tentative. Nevertheless, if the concentration of plutonium in the skull of this subject is approximately equal to the concentration of plutonium in the entire skeleton, the calibration may be valid in spite of the abnormalities. Radiochemical analysis of a portion of the calvaria yielded a result of 170 pCi $^{239}$Pu/g bone ash.[7] Since the total bone ash of this skeleton is estimated to be 1050 g,[6] the total burden calculated from the concentration in the skull is 189 nCi, only 30% greater than the burden

calculated from the injected amount. Thus it appears that the skull is indeed representative of the entire skeleton, in contrast to other bones, such as lumbar vertebra or the tibia.[6]

## Conclusions

Many of the calibration problems encountered in the measurement of plutonium in the lungs in vivo will also be present in the application of this technique. Such problems include the determination of the subject's background of radioactivity (due mostly to $^{40}K$), anatomical variations among subjects, possible external contamination, and an unknown distribution pattern. In addition, the calibration factor for a given individual will change with time, due to redistribution of plutonium within bone by biological processes.

The series of measurements reported here has demonstrated the feasibility of determining skeletal plutonium in vivo by external counting at the skull. Even if the minimum detectable activity calculated above should prove to be too low by an order of magnitude when applied to measurements in vivo, a direct determination of 2.5 times the maximum permissible skeletal burden would be possible.

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# IMPROVEMENT OF THE GENERAL-PURPOSE PLOTTING ROUTINE MYPLOT

R. E. Toohey, J. Rundo, and T. J. Kotek

Major improvements and extensive additions have been made to the general-purpose plotting routine MYPLOT. Computer-generated graphics of publishable quality can be produced with little or no programming effort on the part of the user.

## Introduction

The routine MYPLOT was originally written to provide easy access to the CALCOMP and IBM 2280 film plotters in Argonne's Applied Mathematics Division.[1] In 1976 AMD acquired several new plotting devices, replaced the 2280 with an FR-80, and made several revisions to the "drivers," that is, the programs which translate plotting instructions from a user's program, such as MYPLOT, into machine-language instructions peculiar to the particular plotter being used. Consequently it was necessary to revise MYPLOT, and major improvements were added simultaneously.

Plotting instructions for MYPLOT may be presented as card images via a routine called PLOTIN; alternatively MYPLOT may be called directly from another program, such as one which reads the output of a multichannel analyzer. PLOTIN is extremely easy to use because instructions and data are entered in a "free" format; instructions are entered as meaningful keywords and items of data need be separated merely by a blank space or the end of a card. All the instructions or options have default values designed to produce an acceptable plot, and no programming need be done by the user unless a fairly sophisticated plot is desired. Limitations of MYPLOT are that only one lettering style is used, only rectangular coordinate systems are available, and all jobs must be run on the 370/195; MYPLOT is not available on TSO.

## Improvements

The user now has the option of specifying the sizes of the plotting symbols and the tickmarks. Symbols such as the circle or square can be shaded in so as to appear completely black (white on FR-80 film). Besides

joining the data points with a smooth line, the user can join them with broken, dashed, or dotted lines. Error bars can now be plotted in the x direction, besides the standard error bars in the y direction. Data can be plotted as a histogram, and the bins can be shaded in various fashions. Several sets of data plotted on the same axes can be identified by having their separate titles printed either on top of the frame or at a designated position within the frame, each title preceded by the appropriate symbol or representative line segment.

Alphanumeric information may now be drawn on the plot, in addition to the title and axis labels. Extensive modifications may be made to labels, including over- and underlining, super- and subscripts, and special characters such as male or female symbols, and root and integral signs.

Also, a cataloged procedure has been written in order to minimize the amount of Job Control Language a user must write in order to run MYPLOT and to change his output from one plotting device to another.

Finally, it must be noted that MYPLOT has been designed to match the plotting software and devices available on Argonne's 370/195. It is not likely that the code can be exported for use on other computers or at other facilities. Further information about the program and instructions for its use can be obtained from the authors.

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# DEVELOPMENT OF RADIOCHEMICAL METHOD FOR ANALYZING RADON GAS IN URANIUM MINE ATMOSPHERES*

L. Stein,[+] J. A. Shearer,[†] F. A. Hohorst,[**] and F. Markun

A simplified radiochemical method has been developed for quantitatively analyzing radon gas in underground uranium mines. In this method, a measured volume of air is drawn by a pump through a drying tube and a cartridge containing dioxygenyl hexafluoroantimonate reagent. Radon is captured as a nonvolatile product. After radioactive equilibrium has been established between radon and its short-lived daughters (approximately 4 hr), the gamma-ray emission of the cartridge is measured with a scintillation counter. The amount of radon is then calculated from the gamma-emission rate. The effect of cartridge geometry, reagent load, and air flow rate upon collection efficiency and counting efficiency is reported.

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* Abstract of U.S. Bureau of Mines Report H0252019.

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# THEORY OF THE INDUCTION OF BONE CANCER BY RADIATION: II. A POSSIBLE LOW-LYING LINEAR COMPONENT IN THE INDUCTION OF (BONE) CANCER BY ALPHA RADIATION

John H. Marshall and Peter G. Groer

Target theory is used to determine the relative magnitudes of the linear and square terms of the dose response of a two-target model of cancer initiation by alpha particles. The dose eta at which the linear and square components are equal is derived as a function of the shape and size of the cell nucleus, the probability of cell killing per unit length of track, and the angular distribution of the incident particles. Assuming that 3 MeV alpha particles are incident upon spherical nuclei 7 μm in diameter and that $D_o$ is about 80 rads, eta is 130 rads. If the cells were flattened against bone surface so that their nuclei had a thickness of 1.5 μm, then a bone-surface seeker would yield an eta of about 100 rads, a bone-volume seeker an eta of only 45 rads. Thus, if the two-target nuclear model is correct, surface seekers should have a linear response whereas volume seekers should have a more nearly square response in the dose range just below the plateau in tumor rate. The target calculation is compared to the Kellerer-Rossi formulation for the same problem. If the whole cell nucleus is indeed the relevant volume (site) for cancer initiation, then low LET radiation might produce a square response down to doses as low as a rad.

## Introduction

We have recently shown that it is possible to fit the data for radium in man and in dog by a theory of the induction of bone cancer which involves two initiation events in a single endosteal cell.[1] A priori, these two events could be either one hit on each of two targets or two hits on one target. The one-target option would lead to a response proportional to the square of the dose over the whole dose range. The two-target option would have a square dose-response at high dose and a linear dose-response at low dose. The linear component arises because it is possible to hit both targets with one particle track. The two-target option with its low-linear component appears to be the more promising hypothesis.[1] It is in fact the two-target hypothesis which underlies the Kellerer-Rossi theory of dual radiation action,[2] as we will show below, although they have avoided the concepts of targets and hits.

The two-target option of the two initiation model is promising for a number of reasons.* First, it yields a target size for initiation of about 100 Å in man which seems much more reasonable than the target size of the one-initiation model (0.2 Å).[1] Second, it provides a steep curve of dose response in accordance with the data in the region of dose just below the plateau for radium in man.[1] Third, it yields a linear component at low dose which should provide a good match to the data for radium in mice.[3] Fourth, it predicts that bone-surface seekers should have a more linear curve of dose-response than bone-volume seekers,[1] a prediction that is supported by preliminary analysis of dose response for osteosarcoma induction by alpha particles in mice, rats, dogs, and man.[4] Fifth, it predicts that the curve of dose response for beta particles and other low LET radiation should be at least square with no detectable linear component.[1] Sixth, it can be subjected to experimental test: a collimated beam of alpha particles incident normally on cells flattened to their dishes in culture should transform the cells in proportion to the square of the dose; but alphas incident at glancing angles should have a strong linear component.

This can be appreciated qualitatively by a glance at Figure 1. It is much easier to hit the two targets with one particle (the linear component) if that particle comes in at a glancing angle than if it comes in at right angles. For alpha particles incident normal to the culture dish (or bone), the two targets, randomly positioned in the flattened nucleus, will probably not line up

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*Lloyd, Gemmell, Henning, Gemmell, and Zabransky (this report) have just shown for the first time that normal (mammalian) cells in culture can be transformed to malignant cells by alpha particles. Their technique uses a collimated beam of monoenergetic alpha particles from Argonne's Tandem Van de Graaff which makes possible a number of crucial new experiments on the mechanism of cancer induction by radiation, among which is a test of the angular dependence of transformation frequency. They have also shown that the current notion in the radiation cancer field that one alpha particle through the cell nucleus will probably kill a cell is incorrect, especially for cells flattened against culture dishes or against bone surfaces. These discoveries have opened up the possibility that the action of alpha particles upon cells in producing a cancer initiation may be a direct interaction between an alpha particle track and a DNA molecule.

behind each other; it will take two alphas to hit them (the square component).

We will compare the probabilities of the one-alpha and two-alpha ways of hitting both targets. The result is best expressed as the dose $\eta$ (eta) at which the two probabilities are equal. Then for doses much greater than $\eta$ the response will be square, and for doses much less than $\eta$ the response will be linear. The dose $\eta$ is similar to the Kellerer-Rossi dose $\zeta$ (zeta), but we use a different symbol because we approach the problem using particle tracks, fluences, and target cross sections rather than microdosimetry. This target approach is much simpler than microdosimetry, but it leads toward the same equations. More importantly, target theory seems capable of going more deeply into mechanisms such as the effects of cell killing and of particle type and energy upon target cross section.

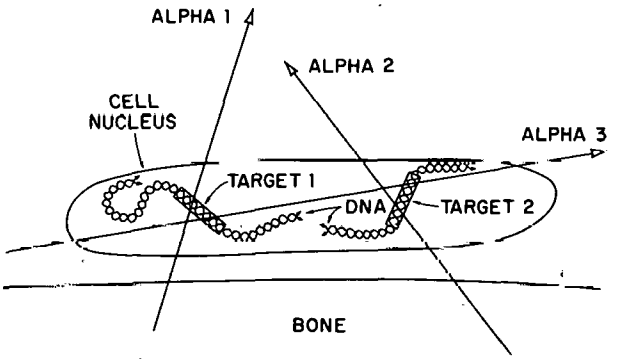


FIG. 1.--Two-target model for the initiation of osteosarcoma by alpha particles. Each target is the order of 100 letters of the genetic code in both strands of a single DNA molecule. The second target is the corresponding message on the homologous chromosome of a pair (Reference 1). Alpha 1 and Alpha 2 give rise to the square component of dose response, Alpha 3, the linear component. (ANL Neg. 149-77-87)

However, before we present a detailed derivation of $\eta$, let us consider a simple case which brings out the essential features of the two-target problem: the origin of the linear component, the essence of the Kellerer-Rossi equation, and approximate values of the dose $\eta$ neglecting cell killing.

A. The Simplest Case

1. Consider a cell nucleus in the form of a rectangular box with sides of length a, a, and c, side a being larger than the thickness c, (Figure 2).

2. Let a collimated beam of monoenergetic alpha particles fall normally on the box so that they see a projected area

$$A = a^2 . \tag{1}$$

3. Let there be two tiny spherical targets of radius b randomly positioned within this nucleus.

4. Then the cross-sectional areas of these targetas as seen by the alpha particles are each $\pi b^2$. Let this target cross section be called $\sigma$.*

$$\sigma = \pi b^2 . \tag{2}$$

5. Let the fluence of alpha particles be n (number per unit area), and assume that all the alphas go completely through a large number of cell nuclei, one of which is the typical nucleus we are considering.

6. Then the probability per cell of a hit on a particular target within our nucleus is

$$p_1 = n\sigma \qquad (p_1 \ll 1) . \tag{3}$$

7. The probability of hitting either target is

$$p_2 = 2n\sigma . \tag{4}$$

8. The probability of one hit on one target by one alpha AND one hit on the other target by another alpha is

$$p_3 = p_2 p_1 = 2n^2\sigma^2 . \tag{5}$$

9. Now let us consider each target as a point and ascribe its radius

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*We will later generalize the meaning of $\sigma$ to the effective cross section, the geometrical cross-sectional area of the target of any shape times the probability that a particular event (such as one or two primary ionizations) will occur. In the final step, this could involve an integration over the whole volume in the vicinity of the target. A "hit" occurs when a particle track through the cell nucleus produces the particular event under consideration. However, it is simpler to visualize the problem if one considers each target as a tiny black sphere and a hit as an intersection of a track and a target. This in no way reduces the power of the solution or prevents its later specialization to particular molecular-level processes.

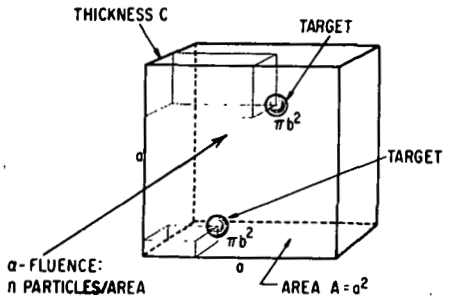


FIG. 2.--The simplest case: a rectangular cell nucleus containing two tiny spherical targets irradiated by a collimated beam of particles normal to one face. Let a = 10 μm and c = 2 μm, for example. (ANL Neg. 149-77-380)

b to every alpha particle track (Figure 3). This procedure is equivalent to considering the track as a line and the target as an area $\pi b^2$. The probability of one hit on a particular target is then the probability that a point lies within the cylindrical volume $\pi b^2 c$. That point target might be anywhere within the nucleus, whose volume is $a^2 c$, so the chance that a particular target is hit by a particular particle track is

$$p_4 = \pi b^2 c/a^2 c = \sigma/A \ . \tag{6}$$

10. The probability that one alpha will hit both targets is then

$$p_5 = p_2 p_4 = 2n\sigma^2/A \ . \tag{7}$$

11. Finally, the total probability per cell of one hit on each of the two targets is the sum of the probabilities for the two processes: $p_5$ for the one-alpha process and $p_3$ for the two-alpha process:

$$p = p_5 + p_3 = 2n\sigma^2/A + 2n^2\sigma^2 \ . \tag{8}$$

12. If we take $2\sigma^2$ out in front,

$$\boxed{p = 2\sigma^2 (n/A + n^2)} \ . \tag{9}$$

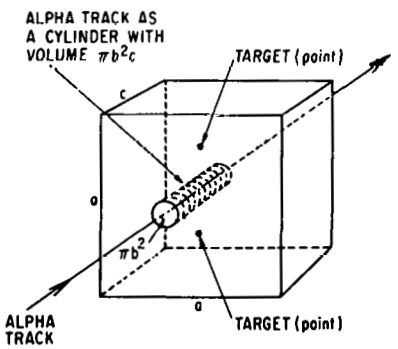


FIG. 3.--Same as Figure 2, except that targets are now points and the portion of the particle track within the nucleus is a cylinder. The cross-sectional area of the cylinder $\pi b^2$ is the effective cross section of each target which takes into account the chance that a significant event occurs within a target). (ANL Neg. 149-77-388)

This is the fluence equivalent of the Kellerer-Rossi equation for our simple case. It indicates that the linear and square terms of dose response are equal when there is, on an average, one alpha particle through the cell nucleus ($nA = 1$ or $1/A = n$). This result is precise no matter which face the particles enter, so long as they enter normal to a face of the box, and so long as one value of the cross section $\sigma$ is applicable to the particle tracks. (We do not yet know the dependence of $\sigma$ upon particle charge or velocity, but an important paper by Platzman and Franck,[5] brought to our attention by Mitio Inokuti, may provide such a link between a particle track and disruption of information in DNA.)

13. We can convert fluence to dose by the formula

$$D = nL/\rho \quad , \tag{10}$$

where L is the LET of the particles and $\rho$ is the density of the tissue. This follows from calculating the dose to a thin semi-infinite slab of tissue irradiated normally by a collimated beam of particles of fluence n and LET L, or by the similar calculation for a small sphere irradiated at any angle.

14. Substituting (10) into (9) and taking $\rho^2/L^2$ out in front,

$$p = 2\sigma^2\rho^2/L^2\,[(L/\rho A)D + D^2] \quad . \tag{11}$$

15. So the dose $\eta$ for which the linear and square terms of (11) are equal is

$$\boxed{\eta = L/\rho A} \qquad \text{Simplest case (no cell killing).} \tag{12}$$

16. If L is in keV/$\mu$m, n is in number/$\mu m^2$, D is in rads, and $\rho = 1$ g/$cm^3$, then (10) becomes

$$D = 16nL \ , \tag{10a}$$

where 16 stands for the conversion factor 16.0 $\mu m^3$-rad/keV ($1.60 \times 10^{-9}$ erg/keV divided by the definition of the rad, 100 erg/g-rad, and by the density of water, $10^{-12}$ g/$\mu m^3$), and (12) becomes

$$\boxed{\eta = 16\ L/A} \qquad \text{Simplest case (no cell killing) L in keV/}\mu\text{m, A in } \mu m^2\text{, } \eta \text{ in rad.} \tag{12a}$$

Alpha particles of 3 MeV (L = 135 keV/μm) incident normally on nuclei of projected area A = 100 $\mu m^2$ should have $\eta$ = 21.6 rads. However, if they are incident from the side so that they see a projected area A = 20 $\mu m^2$, then $\eta$ = 108 rads. Such an effect should provide a clear way of testing the two-target model. (The areas A refer to the suggested dimensions in Figure 2.)

It is also clear from Eq. 12a that beta particles will yield no significant linear component. Their LET is typically less than 1 keV/μm so that $\eta < 1$ rad.

Let us now find what corrections to $\eta$ arise from considering different angles of incidence, nuclei of different shapes, and the competing process of cell killing.

## B. The Effect of Cell Killing in the Simplest Case

Following the same derivation we used in section A, let us see how the initiation probabilities calculated there are affected if we include the probability that the cell must survive the passage of each initiating alpha particle.

1. Let

   $p_s$ = probability of cell survival per track through the nucleus. (13)

2. Then for one hit on one target

$$p_1 = n\sigma p_s \ . \tag{14}$$

3. For one hit on either target

$$p_2 = 2n\sigma p_s \ . \tag{15}$$

4. For two targets hit by two tracks

$$p_3 = p_2 p_1 = 2n^2\sigma^2 p_s^{\ 2} \ . \tag{16}$$

5. For second target on one track

$$p_4 = \sigma/A \ . \tag{17}$$

6. For two targets hit by one track

$$p_5 = p_2 p_4 = 2n\sigma^2 p_s/A \ . \tag{18}$$

7. For two targets hit

$$p = p_5 + p_3 = 2\sigma^2 \ p_s^{\ 2} \ (n/Ap_s) + n^2) \ , \tag{19}$$

8. and inserting expression 10 as before

$$\boxed{\eta = L/\rho A p_s} \qquad \text{Simplest case with cell killing.} \tag{20}$$

Since $p_s$ is less than unity, cell killing increases the value of $\eta$. The linear component is favored because it risks cell death from one particle track, not two. This effect is not taken into account by Kellerer and Rossi. However, in most of the cases for alpha particles we will examine this effect of cell killing increases $\eta$ about a factor of 2. The only exception appears to be the normal incidence of alpha particles upon flattened cells, where $\eta$ is increased only 10% or less.

## C. Nuclei of Any Given (Convex) Shape; No Cell Killing; a Collimated Beam of Particles

1. Consider a nucleus of any convex shape (Figure 4). The values $p_1$, $p_2$, $p_3$ in the simple derivation of section A are unchanged, but we must now modify $p_4$ and $p_5$ because there are now chords of different lengths.

2. The probability of one hit upon a particular target by a particular track of chord c is

$$p_{41} = \pi b^2 c/V = \sigma c/V \ , \tag{21}$$

where V is the volume of the nucleus. We use the same argument as for expression 6, but do not cancel the c's in numerator and denominator.

3. The probability of one hit on either target by a particular track is

$$p_{42} = 2\sigma c/V \ . \tag{22}$$

4. The probability of hitting both targets with a particular track is

$$p_{43} = p_{41}p_{42} = 2\sigma^2 c^2/V^2 \ . \tag{23}$$

5. Averaging $p_{43}$ over all possible chords seen by our collimated beam of particles

$$\overline{p_{43}} = 2\sigma^2 \overline{c^2}/V^2 \ . \tag{24}$$

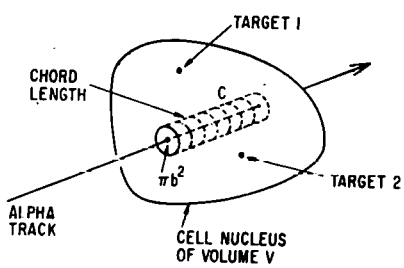


FIG. 4.--Same as Figure 3 except that the nucleus is now of any convex shape (that is, a straight particle track cannot have two segments within the nucleus).
(ANL Neg. 149-77-383)

6. Then with fluence n there are nA tracks through the nucleus, and the probability of hitting two targets with one track is

$$p_5 = nA\,\overline{p_{43}} = 2n\sigma^2\,\overline{c^2}\,A/V^2 \ . \tag{25}$$

7. Now, the volume of a convex shape can be written as the product of the mean chord $\bar{c}$ as seen from a particular direction and the corresponding projected area A (the area of the nucleus as seen by the incident particle):

$$V = \bar{c}A \qquad \text{or} \qquad V^2 = \bar{c}^2 A^2 \ . \tag{26}$$

8. Substituting $V^2$ from (26) into (25),

$$p_5 = 2n\sigma^2 w/A \ , \tag{27}$$

where

$$\boxed{w = \overline{c^2}/\bar{c}^2} \qquad \text{Geometrical correction factor.} \tag{28}$$

For a spherical nucleus, w = 9/8 = 1.13. For the simplest case of section A, w = 1 because all tracks have the same length c.

9. Then

$$p = p_5 + p_3 = 2n\sigma^2 w/A + 2n^2\sigma^2 \ , \tag{29}$$

$$p = 2\sigma^2 (nw/A + n^2) \ . \tag{30}$$

10. Substituting (10) as before

$$p = 2\sigma^2\rho^2/L^2\ [(Lw/\rho A)\,D + D^2] \tag{31}$$

and

$$\boxed{\eta = Lw/\rho A} \qquad \text{Convex nucleus, no killing} \tag{32}$$

## D. The Kellerer-Rossi Equation

1. Kellerer and Rossi[2] postulate that a wide range of biological effects depend upon the square of the specific energy z (local dose) in sites the order of 1 μm in diameter. From the statistical variations of this specific energy, they conclude that a biological effect ϵ depends upon (mean) dose D as

$$\epsilon(D) = k\,(\zeta D + D^2) \ , \tag{33}$$

where

$$\zeta = \overline{z_1^2}/\bar{z}_1 \qquad (34)$$

and $z_1$ = the specific energy to the site from a single ionizing particle and/or its secondaries. They leave the proportionality constant k undefined.

2. Their statistical derivation is practically equivalent to the two-target calculation of section C. This is apparent if we write $z_1$ for case C:

$$z_1 = c\,L/\rho\,V \qquad (35)$$

because a particle of LET L and track length c leaves an energy cL in a site of mass $\rho V$. Our "site" is the mammalian cell nucleus.

3. If we neglect the small increase in L as the particle traverses the nucleus and the small fluctuation in L due to variation in the number of primary ionizations within the nucleus, then we can equate fluctuations in $z_1$ with variations in the chord length for individual tracks within the cell nucleus. Substituting (35) into (34),

$$\zeta = \overline{z_1^2}/\bar{z}_1 = (L/\rho V)(\overline{c^2}/\bar{c}) \,. \qquad (36)$$

4. Substituting $\bar{c} = V/A$ from (26) into (36)

$$\zeta = (L/\rho V)(\overline{c^2}/\bar{c}^2)\,V/A = (L/\rho A)(\overline{c^2}/\bar{c}^2) = Lw/\rho A \;; \qquad (37)$$

just as in expression 31 for the convex nucleus (site) with no cell killing.

So for alpha particles, the Kellerer-Rossi expression for $\zeta$ (34), reduces to the simple two-target expression 12 with correction w (expression 28) for the convexity of the nucleus. The statistical fluctuations of z, which are so prominent in the Kellerer-Rossi approach (expressions 33 and 34), turn out to be not the essence of the problem but only elegant corrections to the basic two-target calculation.

Finally, for induction of bone cancer by beta particles according to the two-target model (expression 12a), the dose $\eta$ is so low that its exact value is not important and the Kellerer-Rossi approach is not necessary.

E. Nuclei of Any Given (Convex) Shape; Cell Killing; a Collimated Beam of Particles

Let us now combine sections B and C to see how cell killing affects the geometrical correction (expression 28).

1. The chance that a target lies on an existing track is

$$p_{41} = \sigma c/V \ , \tag{38}$$

which is the same as expression 21.

2. The chance that a particular target is hit by an alpha which passes through the nucleus AND the cell survives is

$$p_{41s} = \sigma c p_s/V \ , \tag{39}$$

where now $p_s$ is the probability of survival for the particular chord c.

3. Averaging over all chords for a particular angle $\theta$ of the one incident alpha

$$\overline{p_{41s}}\,(\theta) = (\sigma/V)\,\overline{cp_s}\,(\theta) \ . \tag{40}$$

4. Then, if the fluence at angle $\theta$ is $n(\theta)$ and the projected area of the nucleus at angle $\theta$ is $A(\theta)$, the chance of a hit on a particular target is

$$p_1(\theta) = \overline{p_{41s}}\,(\theta)\,n(\theta)\,A(\theta) = (\sigma/V)\,\overline{cp_s}\,(\theta)\,n(\theta)\,A(\theta) \ . \tag{41}$$

5. As before, the chance of hitting either one of the two targets is twice that of hitting a particular one of the two targets, so for one alpha

$$p_{42s} = 2p_{41s} = 2\sigma c p_s/V \tag{42}$$

and for fluence $n(\theta)$

$$p_2(\theta) = \overline{p_{42s}}\,(\theta)\,n(\theta)\,A(\theta) = (2\sigma/V)\,\overline{cp_s}\,(\theta)\,n(\theta)\,A(\theta) \ . \tag{43}$$

6. Then the chance of hitting two targets by two tracks with the fluence $n(\theta)$ is

$$p_3(\theta) = p_2(\theta)\,p_1(\theta) = (2\sigma^2/V^2)\,(\overline{cp_s}\,(\theta)\,n(\theta)\,A(\theta))^2 \ . \tag{44}$$

7. The chance of hitting two targets when there is only one track through the nucleus is

$$p_{43} = p_{41}\,p_{42s} = (\sigma c/V)(2\sigma c p_s/V) \tag{45}$$

$$p_{43} = (2\sigma^2/V^2)\,c^2 p_s \ . \tag{46}$$

Note that the probability for cell survival enters (45) only once because only one track goes through the nucleus, as in expression 18.

8. Averaging over all chords for a particulag angle $\theta$,

$$\overline{p_{43}}(\theta) = (2\sigma^2/V^2)\,\overline{c^2 p_s}(\theta) \ . \tag{47}$$

9. Then for a fluence $n(\theta)$ at angle $\theta$, the chance of hitting both targets with one particle track is

$$p_5(\theta) = \overline{p_{43}}(\theta)\, n(\theta)\, A(\theta) = (2\sigma^2/V^2)\,\overline{c^2 p_s}(\theta)\, n(\theta)\, A(\theta) \ . \tag{48}$$

10. Finally, the chance of hitting both targets in a cell with fluence $n(\theta)$ from a particular angle $\theta$ is

$$p(\theta) = p_5(\theta) + p_3(\theta) \tag{49}$$

$$p(\theta) = (2\sigma^2/V^2)\left[\overline{c^2 p_s}(\theta)\, n(\theta)\, A(\theta) + \left(\overline{cp_s}(\theta)\, n(\theta)\, A(\theta)\right)^2\right]. \tag{50}$$

11. Taking $(\overline{cp_s}(\theta))^2\,(A(\theta))^2$ out in front

$$p(\theta) = (2\sigma^2/V^2)\,(\overline{cp_s}(\theta))^2 (A(\theta))^2 \left[\frac{\overline{c^2 p_s}(\theta)\, n(\theta)}{(\overline{cp_s}(\theta))^2 A(\theta)} + (n(\theta))^2\right]. \tag{51}$$

12. Converting fluence to dose with expression 10, as before,

$$\boxed{\eta = \frac{Lv}{\rho A}} \qquad \begin{array}{l}\text{Convex nucleus,}\\ \text{cell killing,}\\ \text{fluence at one angle ,}\end{array} \tag{52}$$

where

$$\boxed{v = \frac{\overline{c^2 p_s}(\theta)}{(\overline{cp_s}(\theta))^2}} \qquad \begin{array}{l}\text{Geometrical correction factor}\\ \text{with cell killing, fluence at}\\ \text{one angle.}\end{array} \tag{53}$$

13. Note that the probability per track of cell survival, $p_s$, is now included under the averaging sign because $p_s$ depends upon chord length c. Expression 53 takes us away from the Kellerer-Rossi theory (expressions 33 and 34) because v is more complex than w (expressions 37 and 28). The

competition between cell initiation and cell survival for each alpha track makes specific energy z no longer the parameter of interest.

F. The Dependence of Cell Survival on Chord Length

1. The experiment of Lloyd et al.[6] suggests that the probability of cell survival per alpha particle track depends on chord length c. They found that flattened cells irradiated at right angles to the supporting dish showed the expected $D_o$ of about 60 rads, but with chord lengths of only 2 μm within the nuclei, this value of $D_o$ corresponded to 10 to 20 alpha tracks through each nucleus. Yet, the survival curve versus dose was exponential. This remarkable paradox can be explained as follows.

2. Let us assume that there are many small targets for cell killing distributed throughout the nuclear volume, any one of which, if hit, will kill the cell. Then the probability for cell survival from a single track of chord length c will be

$$\boxed{p_s = e^{-\alpha c}} \tag{54}$$

where α is the probability of killing per unit chord length.

3. The dose from x tracks of chord length c through a flat nucleus of projected area A is (expression 10)

$$D = n\bar{L}/\rho = \frac{x}{A}\,\bar{L}/\rho \tag{55}$$

$$\text{or } x = \frac{A\rho D}{\bar{L}} \quad . \tag{56}$$

4. The probability of a cell's survival from the x alpha particles

$$p_{sx} = p_s{}^x = e^{-x\alpha c} \quad . \tag{57}$$

5. Substituting (56) into (57)

$$p_{sx} = e^{\frac{-A\rho\alpha c}{\bar{L}}D} = e^{-\kappa D} \quad , \tag{58}$$

where

$$\kappa = \frac{A\rho\alpha c}{\bar{L}} \qquad \begin{matrix}\text{(Probability per unit}\\ \text{dose of cell killing)}\end{matrix} \tag{59}$$

6. If the nuclei are of any shape and are irradiated from any angle θ,

then

$$\kappa = \frac{\rho\alpha A(\theta)\,\bar{c}(\theta)}{L} \tag{60}$$

but from expression 26, $A(\theta)\,\bar{c}(\theta) = V$, the volume of the nucleus, so

$$\boxed{\kappa = \frac{\rho\alpha V}{L}} \tag{61}$$

or using (10a)

$$\boxed{\kappa = \frac{\alpha V}{16\,L}}$$

$\alpha$ in $\mu m^{-1}$ (Chance of killing per $\mu$m track),
V in $\mu m^3$ (Volume of nucleus),
L in keV/$\mu$m (LET),
$\kappa$ in $rad^{-1}$ . (61a)

7. For $\kappa = 10^{-2}$/rad
V = 180 $\mu m^3$ (Rounded nuclear diameter 7 $\mu$m),
L = 135 keV/$\mu$m (3 MeV alpha particle),
$\alpha = 0.12/\mu m$.

8. Note that the mean lethal dose $D_o = 1/\kappa$ does not depend upon the shape of the nucleus or the angle of irradiation, provided that the targets for cell killing are distributed throughout the nuclear volume, expression 54. If the nuclear membrane contained the targets, there would be a factor of 5 less killing from a given fluence at $\theta = 90°$ than at $\theta = 0°$ for the flattened cells of our simple case (Figure 2), because there would be a factor of 5 fewer penetrations of the nuclear membrane at the same dose.

9. This point can be tested by irradiating flattened cells in vitro at normal and at glancing angles. Thus, we expect no change in $D_o$ but a dramatic change in $\eta$. Killing by alpha particles of less than 10 MeV shows an exponential survival curve versus dose, so probably only one target is involved. On the other hand, our model of initiation (Figure 1) involves two targets. Therefore, for flattened cells, we expect a dramatic change in the shape of the dose-response curve for transformation as a function of the angle of irradiation, but no change in the dose-response curve for cell killing.

G. The Mean Chord and Projected Area of a Cylinder at Different Angles

1. Let us represent the shape of a flattened cell nucleus as a right circular cylinder of radius r and height h. This is a good approximation for the nuclei of cells flattened against their culture dishes or against bone surfaces judging by Lloyd's electron microscope pictures. Let $\theta$ be the angle between the alpha particle tracks and the normal to the flat surface of the cylinder (Figure 5). For the cells used by Lloyd (Heidelberger C3H 10T1/2, clone 8), the mean value of radius r was about 10 $\mu$m (area about 300 $\mu m^2$), height h was about 2.2 $\mu$m.

2. With $\theta = 0°$, the projected area of the cylinder is $A(0) = \pi r^2$.

3. With $\theta = 90°$, the projected area is $A(90°) = 2\,rh$.

4. At intermediate angles, one sees a component of each of these two areas:

$$\boxed{A(\theta) = \pi r^2 \cos\theta + 2\,rh \sin\theta}$$ Projected area, cylinder . (62)

5. The $\cos\theta$ component for the flat surface $\pi r^2$ is obvious, but the $\sin\theta$ component for the curved side of the cylinder also holds, as is shown by considering the spherical triangle PEN in Figure 6. Point E is the intersection of the line of sight EO with the celestial sphere (so large that the cylinder is infinitesimal). The normal to a surface element $h\,r\,d\phi$ on the side of the cylinder intersects the sphere at point N. The projection of the line of sight upon the flat surface of the cylinder intersects the sphere at point P. Then PEN is a spherical triangle with right angle P at point P. Let side NE be the angle $\alpha$ and side PN be the angle $\phi$. Side PE is clearly $90°-\theta$. Now, the component of the area element $h\,r\,d\phi$, seen along line of sight, EO, is clearly $(h\,r\,d\phi)\cos\alpha$. The relation between the three sides and one angle of any spherical triangle gives us

$$\cos\alpha = \cos\phi\cos(90°-\theta) + \sin\phi\sin(90°-\theta)\cos P, \quad (63)$$

but since angle P is 90°, $\cos P = 0$ and (63) reduces to

$$\cos\alpha = \cos\phi\sin\theta \ . \quad (64)$$

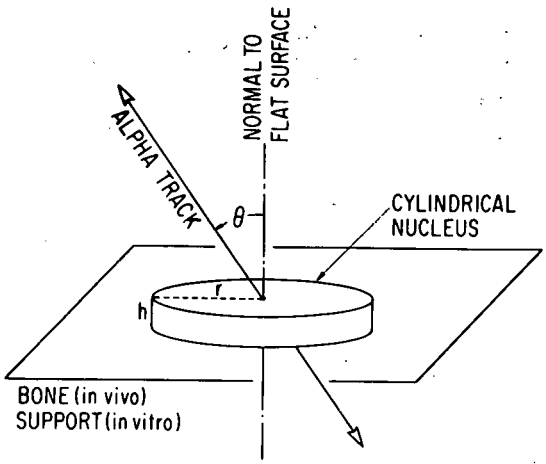


FIG. 5.--Construction for a cell nucleus flattened against a bone surface or against the surface of a culture dish. The nucleus is represented as a right circular cylinder of height h and radius r irradiated at an angle θ to the normal to the flat face.
(ANL Neg. 149-77-379)

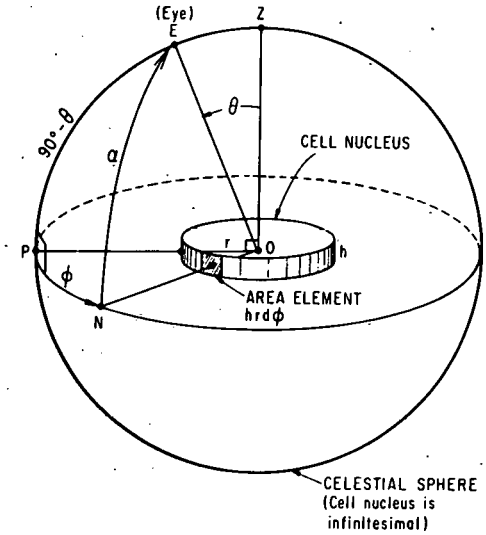


FIG. 6.--Construction to determine the projected area of the rounded side of the cylindrical nucleus (Figure 5) as seen along the line of sight EO. The sphere about point O is analogous to the celestial sphere in navigation; the cylinder at its center is drawn large for clarity but is actually infinitesimal compared to the distance EO.
(ANL Neg. 149-77-387)

6. Then, the total area on the curved side of the cylinder seen from the far-away point E is

$$A(\theta)_{side} = \int_0^{\pi/2} \cos\phi \sin\theta \, h \, r \, d\phi \qquad (65)$$

$$A(\theta)_{side} = 2\, rh \sin\theta \,, \qquad (66)$$

which confirms the second term of expression 62.

7. Since the volume of our cylinder is $V = \pi r^2 h$, the mean chord at angle θ (using expression 26 again) is

$$\bar{c}(\theta) = V/A(\theta) = \frac{\pi r^2 h}{\pi r^2 \cos\theta + 2\, hr \sin\theta} \,. \qquad (67)$$

8. Dividing through by $\pi r^2$, (67) becomes

$$\boxed{\bar{c}(\theta) = \frac{h}{\cos\theta + f\sin\theta} \quad \text{where } f = \frac{2h}{\pi r}}$$ Mean chord cylinder angle $\theta$. (68)

9. When $\theta = 0°$, $\bar{c} = h$, and, of course, all chords are of length h. When $\theta = 90°$, $\bar{c} = \pi r/2$, the mean chord of a circle of radius r, as it should be.

## H. The Dose $\eta$ as a Function of the Angle of Incidence of Alpha Particles in Vitro

1. Now we can calculate the dose $\eta$ for which the linear and square components of dose response should be equal when flattened cells are irradiated with a collimated beam of alpha particles at two different angles in order to provide a test of the two-target model of cancer initiation (Figure 1). To do this, we must evaluate expressions 52 and 53, using expressions 54, 62, and 68.

2. First, consider the value of v in expression 53 for normal incidence ($\theta = 0°$). All chords through the cylindrical nucleus are $c = h$. Therefore, the probability of survival $p_s$ also has a single value and

$$v(0) = \frac{\overline{c^2 p_s(0)}}{(\overline{cp_s}(0))^2} = \frac{c^2 p_s(0)}{(cp_s(0))^2} = \frac{1}{p_s(0)} = e^{\alpha h} , \tag{69}$$

where $p_s$ for $c = h$ has been taken from expression 54.

3. For normal incidence, the dose $\eta$ from expression 52 is then

$$\eta(0) = \frac{Lv(0)}{\rho A(0)} = \frac{Le^{\alpha h}}{\rho \pi r^2} . \tag{70}$$

Expression 70 is, of course, the same as expression 20 with 54 for $p_s$.

4. Since, from expressions 10 and 10a, a dose in rads can be obtained from an LET in keV/$\mu$m and an area in $\mu m^2$ by setting $\rho = 1/16$, as before,

$$\eta(0) = \frac{16\,L e^{\alpha h}}{\pi r^2} \qquad \begin{pmatrix} \text{Dose in rads,} \\ \text{L in keV/}\mu\text{m,} \\ \text{r and h in } \mu\text{m,} \\ \alpha \text{ in } \mu\text{m}^{-1} \end{pmatrix} . \tag{70a}$$

5. The proper value of $\alpha$ to use in expression 70a comes from 61a:

$$\alpha = \frac{16\,L}{D_o V} , \tag{70b}$$

where $D_o$ is the mean lethal dose in rads $(1/\kappa)$, and V is the nuclear volume in $\mu m^3$.

6. Since

$$\alpha h = \frac{16\,Lh}{D_o \pi r^2 h} = \frac{16\,L}{\pi r^2 D_o} , \tag{70c}$$

expression 70a becomes

Normal incidence of alphas in vitro

$$\boxed{\eta(0) = X e^{X/D_o} \quad \text{where } X = \frac{16\,L}{\pi r^2}} ; \tag{70d}$$

$\eta$ and $D_o$ are in rads, L is in keV/$\mu$m, and the projected area of a nuclear $\pi r^2$ is in $\mu m^2$.

7. For Lloyd's cells, $\pi r^2 = 300\ \mu m^2$, the 5.6 MeV alphas have L = 85 keV/$\mu$m, and $D_o$ = 60 rads, so X = 4.5 and $\eta(0)$ = 4.9 rads. Therefore, with normally incident alpha particles of 5.6 MeV, the dependence of transformation upon dose should have a strong square-of-dose component in the dose range above 5 rads.

8. For the extreme case of irradiation at right angles ($\theta = 90°$), the chords of the cylindrical nuclei are the same as the chords of circles, so expression 53 for v must be evaluated for a circle. The distribution f (c) of line segment lengths in any circle of diameter d is

$$f(c) = \frac{c}{d\sqrt{d^2 - c^2}} \qquad \text{(Circle)}, \tag{71}$$

as can be verified by substituting (71) into (72) and using a table of integrals; $\pi r/2$ is $\bar{c}$ for a circle (expression 68) with $\theta = 90°$,

$$\bar{c} \equiv \int_0^d c\, f(c)\, dc = \pi r/2 \qquad (d = 2r) \quad . \tag{72}$$

9.
$$\overline{c^2 e^{-\alpha c}} \equiv \int_0^d c^2 e^{-\alpha c} f(c)\, dc \tag{73}$$

and

$$\overline{c e^{-\alpha c}} \equiv \int_0^d c e^{-\alpha c} f(c)\, dc \tag{74}$$

so the geometrical correction v from expression 53 for $\theta = 90°$ is

$$v(90°) = \frac{\int_0^d c^2 e^{-\alpha c} \frac{c}{d\sqrt{d^2-c^2}}\, dc}{\left[\int_0^d c e^{-\alpha c} \frac{c}{d\sqrt{d^2-c^2}}\, dc\right]^2} , \tag{75}$$

10. Since these integrals could not be found in tables, they were evaluated to within 1/2% by numerical integration, as determined by comparing the result for $\alpha = 0$ with direct integration, which gives

$$\frac{\overline{c^2}}{\bar{c}^2} = \frac{\frac{2}{3} d^2}{(\frac{\pi}{4} d)^2} = 1.081 \quad \text{(Circle)} \quad . \tag{76}$$

(Because both integrands go infinite for $c = d$, the numerical integration used 100 steps between $c = 0$ and $c = 0.99$, and then 100 steps between $c = 0.99d$ and $c = 0.9999d$ to achieve 1/2% accuracy.)

11. The values of v(90°) (expression 53 or 75) are shown in Table 1 for different values of $\alpha d$, the probability per unit track length of killing times the diameter of the flattened cylindrical nucleus.

For comparison with v(90°) values of $e^{\alpha \bar{c}}$ are given for a circle. For values of $\alpha d$ from 0 to 3, which covers the range of interest, values of v(90°) are within 9% of $e^{\alpha \bar{c}}$. Therefore,

$$v(90°) = \frac{\overline{c^2 e^{-\alpha c}}(90°)}{\left(\overline{c e^{-\alpha c}}(90°)\right)^2} \cong e^{\alpha \bar{c}}(90°) \quad , \tag{77}$$

TABLE 1. Values for $\theta = 90°$, Cylinder

| $\alpha d$ | $\overline{c^2 e^{-\alpha c}}$ | $\overline{c e^{-\alpha c}}$ | v | $e^{\alpha \bar{c}}$ | $\frac{v}{e^{\alpha \bar{c}}}$ |
|---|---|---|---|---|---|
| 0 | 0.663 | 0.781 | 1.085 | 1.000 | 1.085 |
| 0.1 | 0.607 | 0.718 | 1.177 | 1.082 | 1.088 |
| 0.3 | 0.509 | 0.607 | 1.383 | 1.266 | 1.092 |
| 0.5 | 0.427 | 0.513 | 1.621 | 1.481 | 1.095 |
| 1.0 | 0.277 | 0.340 | 2.395 | 2.193 | 1.092 |
| 1.2 | 0.233 | 0.289 | 2.790 | 2.566 | 1.087 |
| 1.4 | 0.197 | 0.246 | 3.243 | 3.003 | 1.080 |
| 1.6 | 0.166 | 0.210 | 3.760 | 3.514 | 1.070 |
| 1.8 | 0.140 | 0.180 | 4.350 | 4.111 | 1.058 |
| 2.0 | 0.119 | 0.154 | 5.021 | 4.810 | 1.044 |
| 2.2 | 0.101 | 0.132 | 5.780 | 5.629 | 1.027 |
| 2.4 | 0.085 | 0.113 | 6.636 | 6.586 | 1.008 |
| 2.7 | 0.0667 | 0.0907 | 8.121 | 8.336 | 0.974 |
| 3.0 | 0.0524 | 0.0729 | 9.873 | 10.55 | 0.936 |
| 4.0 | 0.0241 | 0.0366 | 18.01 | 23.14 | 0.778 |
| 5.0 | 0.0116 | 0.0196 | 30.27 | 50.75 | 0.596 |

and we can use the simpler expression $e^{\alpha \bar{c}}$, where $\bar{c} = \pi d/4$ is the mean chord of a circle, for calculating $v(90°)$ and, thence, $\eta(90°)$.

12. The above procedure avoids the difficult problem of calculating the distribution of chord lengths as a function of angle $\theta$ for a right circular cylinder, because we have established that the geometrical correction v never departs from $e^{\alpha \bar{c}}$ more than 9% for any value of the angle $\theta$. At $\theta = 0°$, all chords have the same length h so $v(0)$ is exactly $e^{\alpha \bar{c}}$ (expression 69). At intermediate angles, $v(\theta)$ must lie closer to $e^{\alpha \bar{c}(\theta)}$ than $v(90°)$ lies to $e^{\alpha \bar{c}(90°)}$ in Table 1, because the widest distribution of chord lengths versus angle $\theta$ is that for $\theta = 90°$.

13. Therefore, within the accuracy of the right-hand column of Table 1 we can set

$$v(\theta) \cong e^{\alpha \bar{c}(\theta)} \tag{78}$$

for calculation of $\eta$ both in vitro and in vivo. Expression 78 makes practicable the calculation of $\eta$ as a function of angle in vitro, as well as in vivo, where there are different angular distributions of alpha particles. Then, if necessary, Table 1 could be used to estimate a correction of less than 10% to the final value of $\eta$ in each case.

14. Substituting $v(\theta)$ from (78) into (52),

$$\eta(\theta) = \frac{L\,v(\theta)}{\rho\,A(\theta)} = \frac{L e^{\alpha \bar{c}(0)}}{\rho\,A(\theta)} \quad . \tag{79}$$

15. Substituting $\alpha$ from (60) into (79),

$$\alpha \bar{c} = \frac{\kappa L}{\rho\,A(\theta)\,\bar{c}\,(\theta)} \quad \bar{c}(\theta) = \frac{\kappa L}{\rho\,A(\theta)} \quad , \tag{80}$$

where $1/\kappa = D_o$, the measured mean lethal dose for a cell.

16. Then

$$\eta(\theta) = \frac{L e^{\kappa L/\rho A(\theta)}}{\rho A(\theta)} \quad . \tag{81}$$

17. Using (10, 10a) to convert (81) to conventional units, as before, we finally obtain

$$\boxed{\begin{aligned} &\eta(\theta) = x e^{x/D_o}\,, \\ &\text{where } x = (16\,L)/(\pi r^2 \cos\theta + 2\,rh \sin\theta) \end{aligned}} \tag{81a}$$

(cylindrical nucleus, with cell killing, irradiated at any angle, $\eta$ and $D_o$ in rads, L in keV/μm).

18. For Lloyd's cell nuclei,* r = 10 μm, h = 2.2 μm, L = 85 keV/μm (5.6 MeV alphas), and $D_o$ = 60 rads. Predicted values of $\eta$ versus $\theta$ are given in Table 2.

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*As noted above, these cells were obtained from Heidelberger. We refer to them as Lloyd's cells to indicate the specific dimensions and radiation conditions measured by Lloyd in her experiments detailed in this report.

TABLE 2. $\eta$ for Lloyd's Cells

| Angle $\theta$, deg. | $A(\theta)$, $\mu m^2$ | $x(\theta)$, rads | $\eta(\theta)$, rads |
|---|---|---|---|
| 0 | 314 | 4.35 | 4.7 |
| 45 | 253 | 5.38 | 5.9 |
| 60 | 195 | 6.97 | 7.8 |
| 75 | 124 | 10.98 | 13 |
| 80 | 97.9 | 13.89 | 17 |
| 85 | 71.2 | 19.10 | 26 |
| 90 | 44.0 | 30.91 | 52 |

19. For cells of a more usual nuclear size, r = 5 $\mu$m, h = 2 $\mu$m, V = 180 $\mu m^3$ (rounded diameter 7 $\mu$m), and for 5.6 MeV alpha particles with an initial LET of 85 keV/$\mu$m and a $D_o$ of 60 rads, values of $\eta$ are greater than in Table 2, as shown in Table 3.

TABLE 3. Predicted Values of $\eta$ with Cells of More Usual Nuclear Size[a]

| Angle 0, deg | $A(\theta)$, $\mu m^2$ | $x(\theta)$, rads | $\eta(\theta)$, rads |
|---|---|---|---|
| 0 | 78.5 | 17.3 | 23 |
| 45 | 69.7 | 19.5 | 27 |
| 60 | 56.6 | 24.0 | 36 |
| 75 | 39.6 | 34.3 | 61 |
| 80 | 33.3 | 40.8 | 81 |
| 85 | 26.8 | 50.8 | 118 |
| 90 | 20.0 | 68.0 | 211 |

[a]These are nominal sizes chosen to show the effect of a change in V upon dose response. Measurements are needed.

20. Comparison of Tables 2 and 3 indicates that the predicted change in the shape of the dose-response curve for in vitro transformations as a function of the angle of irradiation by alpha particles should be more easily observed with cells whose nuclear volume is about 180 $\mu m^3$ than with cell nuclei of volume about 680 $\mu m^3$, as used so far by Lloyd et al. The angular dependence of $\eta$ in Table 3 shows that the best test of the theory would be a measurement of transformations versus dose in the range 20–100 rads at $\theta = 0°$ (normal incidence) and at $\theta = 85°$ (glancing incidence).

## I. The Angular Distribution of Alpha Particles from a Bone-Surface Source in Vivo

1. Consider the alpha particle fluence at point P a distance x from a bone-surface source of alpha particles (Figure 7).

2. Let S be the number of alphas emitted per unit area of bone surface (in all directions).

3. Then, all the particles which arrive at point P with angles between $\theta$ and $\theta + d\theta$ from the normal to the bone surface originate in the circular band between y and y + dy.

4. The area of this band is $2\pi y\, dy$. The number of emissions is $S(2\pi y)dy$.

5. Since the geometry of every point within this circular band with respect to point P is identical to that of point B, let us concentrate these

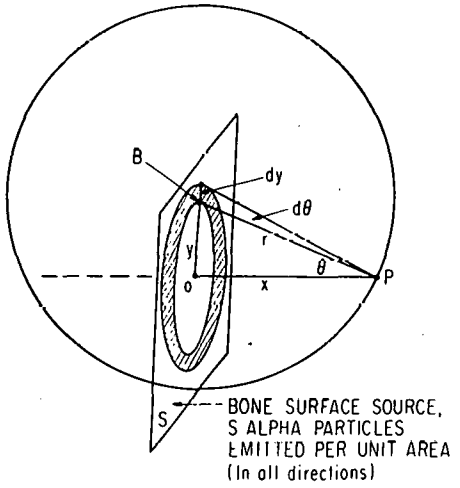


FIG. 7.--Construction for the fluence of alpha particles arriving at point P at angle $\theta$ from the bone surface S, which emits (in all directions) a number S particles per unit area of source. (ANL Neg. 149-77-386)

emissions at point B and determine the resultant fluence dn at point P:

$$dn = \frac{S(2\pi y)\,dy}{4\pi r^2} \quad , \tag{82}$$

where $4\pi r^2$ is the area of the sphere of radius r about point B.

6. Since $y = r\sin\theta$, and $\cos\theta\,dy = r\,d\theta$, expression 82 reduced to

$$\boxed{dn = \frac{S}{2}\tan\theta\,d\theta}$$ Angular distribution of fluence for a bone-surface source. (83)

7. The total fluence at point P is

$$\boxed{n = (S/2)\int_0^{\cos^{-1}(x/R)} \tan\theta\,d\theta = (S/2)\ln(R/x)} \quad . \tag{84}$$

8. Converting fluence to dose with expression 10a, the dose at point P from surface source S is

$$\boxed{D = 16\,nL = 8\,S\,L\ln(R/x)} \quad , \tag{84a}$$

where x is the distance from the bone source in μm,

L is the LET of the particles in soft tissue calculated as E/R, keV/μm,
S is the number of alphas emitted per $\mu m^2$ of bone surface,
E equals initial energy of particle in keV,
D is the dose in rads,
R is the range in soft tissue in μm.

9. Note that we are <u>not</u> introducing error here by using a constant LET calculated as E/R. Our calculations are based upon particle fluence (expressions 83, 84), not dose. Dose is used only in the expressions with expression numbers which include a letter, such as (84a) or (10a), to make contact with familiar formulae and to make fluence results easier to remember. The essential point is that the cross section for killing or initiation is not, in general, proportional to dose, microdose, or specific energy. Therefore, a correction to expression 84a for the Bragg curve of LET versus residual energy of the alpha particle is perhaps not relevant to the problem. It depends upon

the shape of the curve of the particular cross section versus LET in the range of interest.

10. It follows from integration of (84a) that the average dose between 0 and x μm from the bone surface is

$$\boxed{\overline{D} = 8\ SL(1 + \ln(R/x))} \qquad (84b)$$

with the same units as in (84a). This is identical to the formula calculated by Mays[7] and used by us[8] for the endosteal dose from a surface source, which provides a double check on expressions 83 and 84.

## J. The Angular Distribution of Alpha Particles from a Bone-Volume Source

1. First let us consider the line AB in Figure 8 as bone surface, with inactive soft tissue to the right and a volume source of alpha particles to the left. For simplicity, we will first consider the volume source as soft tissue like that to the right of line AB. (In the last step we make a change of scale from tissue density to bone density.)

2. If the number of alpha particles emitted in all directions per unit volume of the volume source is V, then the number emitted in all directions from the volume element $2\pi y\ dy\ dx$ is $V\ (2\pi y\ dy)\ dx$. Note that the rectangle CDEF has the same area as the parallelogram ABCD, which contains all the alpha emissions which can reach point P at angle θ.

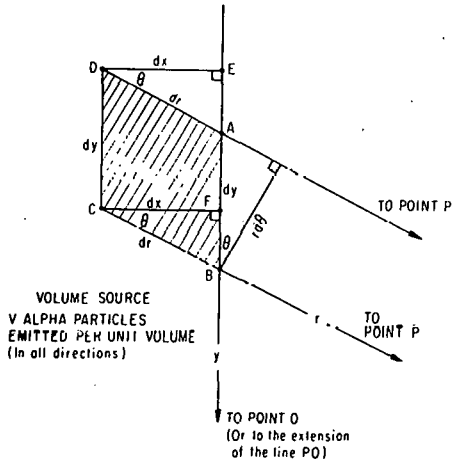


FIG. 8.--Construction for the fluence arriving at point P at angle θ from a volume source of alpha particles as derived from the result for a surface source.
(ANL Neg. 149-77-381)

3. Since dx is an infinitesimal, this volume element of alpha emissions is equivalent to the surface element in the previous section (I), or

$$V(2\pi y\, dy)\, dx = S\,(2\pi y\, dy)\ . \tag{85}$$

4. Therefore, we can use expression 83 from the previous section to write an expression for the fluence at point P between $\theta$ and $\theta + d\theta$ due to the volume source of thickness dx:

$$dn = \frac{V}{2} \tan\theta\, d\theta\, dx\ , \tag{86}$$

where we have replaced S by V dx, from expression 85.

5. Now it is clear from Figure 8 that

$$dx = \cos\theta\, dr\ , \tag{87}$$

so substituting (87) into (86),

$$dn = (V/2)\ \sin\theta\, d\theta\, dr\ . \tag{88}$$

6. Integrating (88) from $r_{min}$ to R for a given angle $\theta$ gives all the fluence at point P between $\theta$ and $\theta + d\theta$ from the (soft tissue) volume source.

$$dn = (V/2)\sin\theta\, d\theta \int_{r_{min}}^{R} dr = (V/2)\sin\theta\,(R - r_{min})d\theta\ , \tag{89}$$

where R is the range of the alpha particle in soft tissue.

7. From Figure 7 it is clear that for any given angle $\theta$,

$$r_{min} = X/\cos\theta\ , \tag{90}$$

where X is the distance of point P from the surface of the volume source.

8. Inserting (90) into (89),

$$dn = (V/2)\ \sin\theta\,(R - X/\cos\theta)\, d\theta = (V/2)(R\sin\theta - X\tan\theta)d\theta. \tag{91}$$

9. Bringing R out in front,

$$dn = (VR/2)(\sin\theta - (X/R)\tan\theta)\, d\theta\ . \tag{92}$$

10. Now let us increase the density of the volume source from that of tissue to that of bone. For example, let us double the density. If we halve dr and dx in Figure 8 and double V so that $V_{bone} = 2\ V_{tissue}$, nothing in our derivation changes. We have simply made a change of scale within the

volume source. This change of scale can be represented by $R_{bone}/R_{tissue} = 1/2$, because particle ranges are inversely proportional to density. Then it follows that

$$V_{bone} R_{bone} = V_{tissue} R_{tissue} , \tag{93}$$

where $V_{bone}$ is the number of alpha emissions per unit volume of bone which is equivalent to $V = V_{tissue}$ in expression 92.

11. Therefore, we can replace VR in expression 92 by $V_{bone} R_{bone}$ to convert it from a volume source of soft tissue (our derivation so far) to a volume source of bone:

Angular distribution of fluence at P from a bone volume source

$$\boxed{dn = (V_{bone} R_{bone}/2)(\sin\theta - (X/R)\tan\theta)\, d\theta} \tag{94}$$

where $V_{bone}$ is the number of alphas emitted per unit volume of bone,

$R_{bone}$ is the range of alphas in bone,

X is the distance of point P from bone surface,

R is the range of the alphas in soft tissue, and

dn is the fluence at point P (number/area) arriving at an angle between $\theta$ and $\theta + d\theta$, measured from the nomral to the bone surface.

12. Integrating expression 94 we get the total fluence at point P from a bone volume source:

$$n = (V_{bone} R_{bone}/2) \int_0^{\cos^{-1}(X/R)} (\sin\theta - (X/R)\tan\theta)\, d\theta \tag{95}$$

$$\boxed{n = (V_{bone} R_{bone}/2)(1 - X/R + (X/R)\ln(X/R))} . \tag{96}$$

13. Converting to dose in rads with expression 10a, the dose at distance x is

$$\boxed{D = 16\ nL = (8\ V_{bone} R_{bone} E/R)(1 - X/R + (X/R)\ln(X/R))} . \tag{96a}$$

14. Averaging (96a) from X= 0 to X=X μm from bone surface;

$$\boxed{\overline{D} = (8 V_{bone} R_{bone} E/R)(1 - 3X/4R + (X/2R)\ln(X/R))} \quad , \qquad (96b)$$

where $V_{bone}$ is the number of alphas emitted per unit volume of bone ($\mu m^{-3}$),

$R_{bone}$ is the alpha range in bone in μm,

R is the alpha range in soft tissue in μm,

X is the distance of point P from bone surface in μm,

E is the initial alpha energy in keV,

E/R is the LET in keV/μm (see paragrapm I.9 above),

$\overline{D}$ or D is the dose in rads.

15. Expression 96b is identical to that calculated by Mays[7] and used by us[8] for the endosteal dose from a volume source, which double checks (94) and (96).

## K. The Dose η for an Angular Distribution of Particles, a Convex Nucleus, and Cell Killing in Vivo

1. Taking expressions 44 and 49 and substituting dp for p and dn for n, we find the probability of hitting both targets in a convex nucleus with a fluence dn(θ) between angle θ and θ + dθ is

$$dp(\theta) = dp_5(\theta) + dp_2(\theta)dp_1(\theta) \ . \qquad (97)$$

2. Substituting expression 48 for $dp_5(\theta)$, 43 for $dp_2(\theta)$, and 41 for $dp_1(\theta)$ into (97) and then integrating over all values of θ seen at point P,

$$p = (2\sigma^2/V^2)\left[\int \overline{c^2 e^{-\alpha c}}(\theta) A(\theta)\, dn(\theta) + \left(\int \overline{c\, e^{-\alpha c}} A(\alpha)\, dn(\theta)\right)^2\right], \qquad (98)$$

where $e^{-\alpha c}$ has been substituted for $p_s$, using expression 54.

3. Now, from Table 1 (section H) it is clear that for θ = 90° we can approximate

$$\overline{c^2 e^{-\alpha c}}(\theta) \quad \text{by} \quad \overline{c}^2(\theta)\, e^{-\alpha \overline{c}(\theta)} \qquad (99)$$

and

$$\overline{c\, e^{-\alpha c}}(\theta) \quad \text{by} \quad \overline{c}(\theta)\, e^{-\alpha \overline{c}(\theta)} \qquad (100)$$

without incurring as much as 10% error so long as $\alpha d$ lies between 0 and 3, the range of interest. In the integrations over many angles of $\theta$ in expression 98, the error must be less than that for $\theta = 90°$ because, as noted before, the circular aspect of the cylinder ($\theta = 90°$) has a wider distribution of chord lengths c than any other angle. Note particularly that (99) and (100) are used only for the mean chord at each angle $\theta$. The subsequent integration over $\theta$ (below) is exact.

4. Therefore, we can rewrite (99) as

$$p = (2\sigma^2/V^2)\left[\int \bar{c}^2 e^{-\alpha\bar{c}} A\,dn + \left(\int \bar{c} e^{-\alpha\bar{c}} A\,dn\right)^2\right] \quad . \quad (101)$$

5. Replacing $\bar{c}A$ by V, the nuclear volume, within each integral sign using expression 26, and dividing and multiplying each of the integrals by the total fluence n, we get

$$p = (2\sigma^2/V^2)\left[V\left(\int \bar{c} e^{-\alpha\bar{c}} dn/n\right) n + V^2\left(\int e^{-\alpha\bar{c}} dn/n\right)^2 n^2\right] . \quad (102)$$

6. Taking $V^2\left(\int e^{-\alpha\bar{c}} dn/n\right)^2$ out in front,

$$\boxed{p = 2\sigma^2\left(\int e^{-\alpha\bar{c}} dn/n\right)^2 \left[\left(\frac{1}{V}\frac{\int \bar{c} e^{-\alpha\bar{c}} dn/n}{\left(\int e^{-\alpha\bar{c}} dn/n\right)^2}\right) n + n^2\right]} \quad . \quad (103)$$

Expression 103 is now in the same form as the simple expression 9.

7. Converting fluence to dose using expression 10a, our final expression for the dose $\eta$, the dose in rads at which the linear and square terms of dose response are equal for a bone seeker in vivo is

Angular distribution of fluence, convex nucleus, cell killing

$$\boxed{\eta = (16\ L/V)\frac{\int_0^{\theta_{max}} \bar{c}(\theta)\, e^{-\alpha\bar{c}(\theta)}\, dn(\theta)/n}{\left(\int_0^{\theta_{max}} e^{-\alpha\bar{c}(\theta)}\, dn(\theta)/n\right)^2}} \quad (103a)$$

where

$\eta$ is in rads,

L is the LET in keV/$\mu$m,

V is the volume of the cell nucleus in $\mu m^3$,

n is the total fluence at point P in $\mu m^{-2}$,

$\bar{c}(\theta)$ is the mean chord of the cell nucleus as seen at angle $\theta$,

$\alpha$ is the probability of reproductive death of the cell per unit track length of an alpha particle,

$\theta_{max} = \cos^{-1}(X/R)$, the maximum angle of incidence seen at point P,

X is the distance of the point P from bone surface ($\mu$m),

R is the range of the alpha particles in soft tissue ($\mu$m).

8. We evaluate expression 103a by numerical integration using (68) for $\bar{c}$, and (61a) for $\alpha$. We use L = 135 keV/$\mu$m (the LET of a 3 MeV alpha particle in tissue, or the mean LET of a typical alpha particle of initial energy 5.5 MeV). The results are plotted in Figure 9.

9. We take point P to be at the center of the cell nucleus. For bone surface sources, we use (83) for dn and (84) for n. For bone volume sources, we use (94) for dn and (96) for n.

## L. The Dose $\eta$ for a Spherical Nucleus with Cell Killing

1. The chord length distribution for a sphere of diameter d is

$$f(c) = \frac{2c}{d^2} \quad . \tag{104}$$

2. Therefore, expression 53 becomes

$$v = \frac{\int_0^d c^2 e^{-\alpha c} \left(\frac{2c}{d^2}\right) dc}{\left[\int_0^d c\, e^{-\alpha c} \left(\frac{2c}{d^2}\right) dc\right]^2} \quad . \tag{105}$$

3. The solution to (105) is

$$v = \frac{3x^2}{4}\left[\frac{1 - e^{-x}(1 + x + x^2/2 + x^3/6)}{(1 - e^{-x}(1 + x + x^2/2))^2}\right], \qquad (106)$$

where $x = \alpha d$, d = diameter of sphere, $\alpha$ = probability of killing per unit track length. Values of v are shown in Table 4, together with the dose $\eta$ from expression 52 converted to rads as in expressions 12 and 12a. The dose $D_o$ comes from expression 61a.

## M. Conclusions

The mean lethal dose to resting cells from 3 MeV alphas probably lies between 56 rads and 112 rads, so for spherical nuclei, the value of $\eta$ is comparable to, or exceeds, $D_o$. Since the onset of the plateau in tumor rate lies at $\sqrt{2}\, D_o$, there should be no discernible square-of-the-dose region in the dose-response curve for spherical nuclei according to the two-target model; the linear component should dominate right up to the plateau in tumor rate. Since there appears to be a square-of-the-dose region in the human radium data, the nuclei of the risk cells are probably not spherical, as one would expect if they were somewhat off bone surface. If the risk cells are flattened against bone surface (Figure 9), then for bone volume seekers the dose $\eta$ probably lies below $D_o$ so that the square component of dose response on the two-target model should be dominant just below the plateau.

If the flattened nucleus is 1.5 μm thick, a bone-volume source should have $\eta \cong 45$ rads and a bone-surface source should have $\eta \cong 100$ rads. For a spherical nucleus off bone surface, $\eta$ would be still larger (angular distribution of the alphas is irrelevant for a sphere; (Table 4).

Therefore, if the two-target model (Figure 1) is correct, then the endosteal cells at risk are probably flattened against bone surface rather than rounded and off bone surface. Bone surface seekers may be expected to show linear curves of dose response for all doses below the plateau. Bone volume seekers may be expected to show a region of more nearly square dose response between the dose $\eta$ and the dose $\sqrt{2}\, D_o$; below $\eta$ the response should be linear.

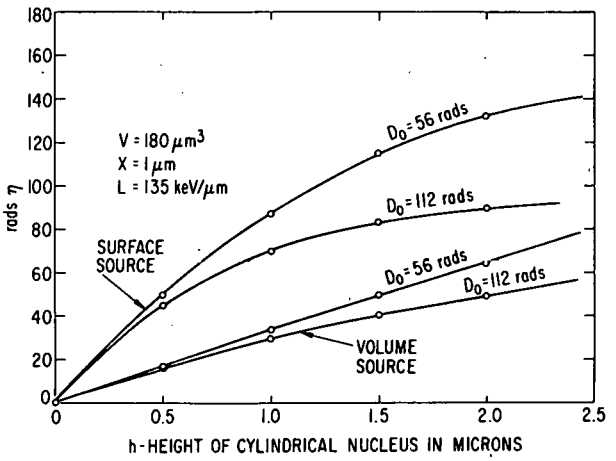


FIG. 9.--The dose η as a function of the thickness h of the (cylindrical) cell nucleus as flattened against bone surface and the mean lethal dose for a cell. The center of the nucleus of volume V = 180 $\mu m^3$ is taken to be a distance x = 1 μm from bone surface. An effective LET of 135 keV/μm is assumed. The upper two curves are based upon the angular distribution of alpha particles from a bone-surface source, the lower two curves are for a bone-volume source. For comparison, the dose η would be 105 rads ($D_o$ = 112 rads) and 170 rads ($D_o$ = 56 rads) if the cell nuclei were spherical (Table 4) and then the result would be independent of the type of bone seeker.

TABLE 4. The Geometrical Correction v for a Spherical Nucleus as a Function of Cell Killing, αd

| αd | v | $D_o$, rads[a] | η, rads[a] | |
|---|---|---|---|---|
| 0 | 1.125 | ∞ | 63 | (No killing) |
| 0.3 | 1.385 | 280 | 78 | |
| 0.5 | 1.587 | 168 | 89 | |
| 0.75 | 1.875 | 112 | 105 | |
| 1.0 | 2.209 | 84 | 124 | (Values of Interest) |
| 1.5 | 3.032 | 56 | 170 | |
| 2.0 | 4.100 | 42 | 230 | |
| 2.5 | 5.461 | 34 | 307 | |
| 3.0 | 7.157 | 28 | 402 | |

[a]The two columns on the right give the corresponding mean lethal dose $D_o$ and the dose η for 3 MeV alpha particles (135 keV/μm) and a sphere of diameter d = 7 μm.

This applies, of course, to alpha emitters. For beta emitters, dose $\eta$ is less than 1 rad so that they should show a square response over the whole range of doses from below 1 rad to their plateau at many hundreds of rads.

More measurements of the volume, thickness, and position of the nuclei of endosteal cells are clearly needed, and a test of the angular dependence of transformations of cells in vitro by a collimated beam of alpha particles (section H) appears to be crucial.

## N. The Predicted Shape of the Dose Response Curve in Vivo

1. The square component of the two-initiation model for tumor rate we will designate $P_2$,

$$P_2 = \frac{\sigma_2^2 \lambda s}{\kappa^2} (1 - e^{-\kappa D} - \kappa D e^{-\kappa D}) , \tag{107}$$

where $\sigma_2$ is the probability per rad of one initiation by each of two alphas (Eq. 24, Ref. 1).

2. The linear component $P_1$ has the form

$$P_1 = \frac{\sigma_1 \lambda s}{\kappa} (1 - e^{-\kappa D}) , \tag{108}$$

where $\sigma_1$ is the probability per rad of two initiations by one alpha (Eq. 21, Ref. 1).

3. The derivation of the dose $\eta$ in this paper did not take into account the killing of initiated cells by alpha particles subsequent to the initiating alpha or alphas. Therefore, it is the low-dose asymptotes of (107) and (108) that are equal at the dose $\eta$.

4. For $\kappa D \ll 1$,

$$P_2 = \sigma_2^2 \lambda s D^2/2 \tag{109}$$

and

$$P_1 = \sigma_1 \lambda s D . \tag{110}$$

5. Then $P_1 = P_2$ when $D = \eta$, so

$$\sigma_1 \lambda s \eta = \sigma_2^2 \lambda s \eta^2/2 \qquad (111)$$

6. or

$$\sigma_1 = \sigma_2^2 \eta/2 \ . \qquad (112)$$

7. Substituting (112) into (108), adding (107) and rearranging, the total tumor rate P from both the linear component $P_1$ and the square component $P_2$ is

$$\boxed{P = P_o y(1 - e^{-x} - xe^{-x}/y)} \quad \text{Shape of the dose response curve in vivo} \ , \qquad (113)$$

where

$P_o = \sigma^2 \lambda s/\kappa^2$ = the plateau in tumor rate of the square component ($\eta = 0$)

$\sigma = \sigma_2$ = the probability per rad of each initiation in the two-particle process,

$y = 1 + \eta\kappa/2$ ($\eta$ is the dose calculated in this paper),

$x = \kappa D = D/D_o$ = the dose in units of the mean lethal dose to a cell.

8. Expression 113 gives the shape of the dose-response curve for long-term alpha emitters in vivo: tumor rate versus endosteal dose. Figure 10 is a plot of expression 113 for tumor rate as a function of the dimensionless parameters, $\kappa D$ and $\eta\kappa$. Note that in Figure 10, $\eta\kappa = 0.1$ shows the effect of the linear component at low doses, the square component at intermediate doses, and the plateau at high doses.

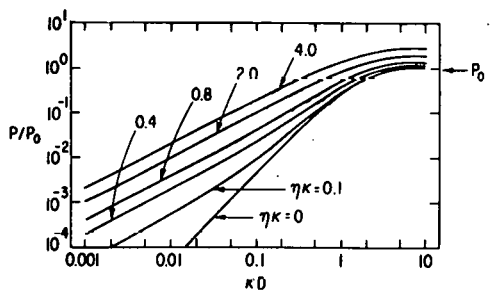


FIG. 10.--The predicted dose response in vivo ($P/P_o$) as a function of the parameter $\eta\kappa$ and $\kappa D$ (expression 113). This is a new three-parameter algebraic model of dose response: tumor rate P versus endosteal dose D with parameters $P_o$, $\kappa$, and $\eta$. On the two-target model (Figure 1), these parameters are directly related to mechanisms in vivo. (ANL Neg. 149-77-389)

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## APPENDIX A. Exposure Data for Radium Patients

Table 1 summarizes exposure data collected as of 31 December 1976 for 1933 radium cases under study at the Center for Human Radiobiology. It includes all persons measured for radium since the start of the Center in 1969 and all persons for whom we have analysis data from earlier work at the Radioactivity Center of the Massachusetts Institute of Technology, the New Jersey Radium Research Project of the New Jersey Department of Health, and the Argonne Radium Studies at the Argonne National Laboratory and the Argonne Cancer Research Hospital.

The corresponding table in the 1976 annual report[1] listed 1832 cases. The radium burdens of 91 living persons and 4 exhumed remains were measured for the first time in 1976. Six cases not previously listed have been added because reports of measurements made in prior years were located. The 101 new cases are identified by a star following the year of measurement. There were follow-up examinations and burden measurements in 1976 on 114 previously listed persons. Changes in basic data for several of the previously listed cases are due to review of information on exposure histories and to reassessment of old measurement data.

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

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

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

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[2] |
| 9 | Initial ratio of $^{228}Ra$ to $^{226}Ra$ probably ≤ 0.20[2] |
| L | 90% confidence limits extend from 0.0 nCi to an upper limit between 4 and 8 nCi |

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

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

The last four columns of Table 1 give quantities calculated from the measured body burdens and exposure data shown in the other columns. For many cases, the number of significant digits shown obviously exceeds the number justified by the accuracy of the basic data, and the errors indicated for the latter should be applied to the derived quantities. The columns under "INPUT" give the amounts of initially acquired $^{226}Ra$ and $^{228}Ra$ expressed as 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 ionization dose to the skeleton[4]—either up to the date of death or, for the living subjects, through 1976. Except for the foetal skeleton (case 01-579), the results in the last two columns were calculated with standard skeletal masses of 5 kg for women and 7 kg for men. It should be noted that "INPUT" was expressed as nanocuries per gram of bone (nCi/g) in previous Annual Reports, and the numerical values were therefore 5 times smaller for women and 7 times smaller for men than are shown in Table 1 of this report. The change was made partly for convenience and partly to avoid confusion as to whether skeletal or whole body masses were involved.

References

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

TABLE 1 EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 | 1921 | 234 | 1969 | 2650 | A1 | 0.00490 | A2 | 230 | 283 | 728 | 2035 |
| 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 |
| 00-027 | F | 1902 | 1942 | 01 | 1918 | 130 | 1970 | 2500 | A1 | 0.00023 | F3 | 505 | 55 | 4187 | 808 |
| 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 | 74 | 0 |
| 00-033 | M | 1868 | 1922 | 06 | 1919 | 156 | 1970 | 6 | A6 | 0.00300 | Z7A | 0 | 0 | 0 | 0 |
| 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 | 1967 | 4650 | A1 | 0.0 | Z9A | 794 | 0 | 5380 | 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 | 780 | 1935 | 200 | E4 | 0.0 | Z9 | 30 | 0 | 281 | 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 | 1971 | 1210 | B1 | 0.00322 | B2 | 343 | 217 | 4629 | 3267 |
| 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 |

*New case.

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-020 | 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 | G4 | 0.0 | 79 | 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 | 1919 | 156 | 1943 | 1140 | B2 | 0.02190 | F3 | 229 | 77 | 2525 | 1149 |
| 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 | 27 | 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 | 25 | 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 | 29 | 30 |
| 01-044 | F | 1904 | | 01 | 1924 | 22 | 1959 | 4 | B3 | 0.08000 | Z2B | 1 | 6 | 14 | 83 |
| 01-045 | F | 1889 | | 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 | 306 | 2047 |
| 01-048 | F | 1900 | | 01 | 1920 | 206 | 1957 | 140 | B2 | 0.09290 | F2 | 35 | 230 | 513 | 3455 |
| 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 | 4 | 6 |
| 01-051 | F | 1904 | | 01 | 1923 | 162 | 1957 | 150 | B2 | 0.13330 | D5 | 36 | 251 | 513 | 3780 |
| 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 | 17 | 87 |
| 01-056 | F | 1904 | | 01 | 1920 | 364 | 1965 | 134 | B1 | 0.03432 | B2 | 37 | 206 | 533 | 3092 |
| 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 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-060 | F | 1909 | | 07 | 1923 | 20 | 1974 | 0 | B6 | 0.00330 | Z8B | 0 | 0 | 0 | 0 |
| 01-063 | F | 1911 | | 01 | 1927 | 213 | 1976 | 34 | B1 | 0.00154 | Z8B | 10 | 5 | 132 | 69 |
| 01-066 | F | 1904 | | 01 | 1925 | 0 | 1975 | 0 | B6 | 0.00290 | Z8B | 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 | 347 | 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 | 1976 | 6 | B3 | 0.00246 | Z8B | 2 | 2 | 24 | 24 |
| 01-075 | F | 1902 | | 01 | 1922 | 52 | 1976 | 2 | B6 | 0.01024 | Z2B | 1 | 4 | 9 | 65 |
| 01-078 | F | 1909 | | 01 | 1925 | 40 | 1974 | 4 | B6 | 0.00313 | Z8B | 1 | 1 | 17 | 21 |
| 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 | 438 | 2254 |
| 01-081 | F | 1907 | | 01 | 1923 | 11 | 1959 | 7 | B6 | 0.08000 | Z2B | 2 | 11 | 26 | 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 | 196 | 1110 |
| 01-085 | F | 1913 | | 01 | 1927 | 47 | 1958 | 6 | B6 | 0.02200 | Z8B | 1 | 1 | 19 | 19 |
| 01-086 | F | 1907 | 1966 | 01 | 1925 | 4 | 1959 | 0 | B6 | 0.08000 | Z2B | 0 | 0 | 0 | 0 |
| 01-087 | F | 1905 | | 01 | 1921 | 344 | 1964 | 780 | F4 | 0.03690 | F1 | 213 | 1061 | 3027 | 15953 |
| 01-090 | F | 1910 | | 01 | 1927 | 90 | 1974 | 6 | B3 | 0.00313 | Z8B | 2 | 2 | 24 | 22 |
| 01-091 | F | 1907 | | 01 | 1927 | 264 | 1974 | 0 | B6 | 0.00327 | 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 | 1925 | 3 | 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 | | 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 | 82 | 64 |
| 01-097 | F | 1905 | | 01 | 1921 | 110 | 1963 | 122 | B1 | 0.03852 | B2 | 33 | 187 | 485 | 2808 |
| 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 |
| 01-105 | F | 1898 | 1945 | 01 | 1921 | 21 | 1963 | 460 | A1 | 0.05217 | A1 | 95 | 801 | 812 | 11743 |
| 01-106 | F | 1902 | | 01 | 1924 | 155 | 1959 | 10 | B2 | 0.08000 | Z2B | 2 | 12 | 35 | 187 |
| 01-110 | F | 1909 | | 01 | 1925 | 93 | 1974 | 3 | B6 | 0.00313 | Z8B | 1 | 1 | 12 | 15 |
| 01-111 | F | 1910 | | 01 | 1927 | 15 | 1974 | 2 | B6 | 0.00313 | Z8B | 1 | 1 | 8 | 8 |
| 01-112 | F | 1908 | 1955 | 01 | 1924 | 835 | 1960 | 80 | F4 | 0.07000 | F1 | 19 | 92 | 185 | 1368 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-113 | 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 | 34 | 44 |
| 01-122 | F | 1912 | | 01 | 1927 | 49 | 1975 | 11 | B2 | 0.00290 | Z8B | 3 | 3 | 44 | 46 |
| 01-123 | F | 1889 | | 01 | 1923 | 11 | 1976 | 0 | B6 | 0.01024 | Z2B | 0 | 0 | 0 | 0 |
| 01-124 | F | 1909 | | 01 | 1927 | 64 | 1973 | 55 | B2 | 0.00370 | Z8B | 16 | 15 | 215 | 221 |
| 01-125 | F | 1911 | | 01 | 1927 | 5 | 1974 | 0 | B6 | 0.00327 | Z8B | 0 | 0 | 0 | 0 |
| 01-126 | F | 1903 | 1969 | 01 | 1922 | 416 | 1969 | 150 | A1 | 0.03133 | A3 | 43 | 318 | 556 | 4786 |
| 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 |
| 01-130 | F | 1909 | | 01 | 1926 | 196 | 1964 | 11 | B2 | 0.01140 | Z8B | 3 | 3 | 38 | 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 | 42 | 64 |
| 01-136 | F | 1907 | | 01 | 1923 | 185 | 1976 | 35 | B2 | 0.00858 | B3 | 11 | 48 | 152 | 728 |
| 01-137 | F | 1901 | | 01 | 1923 | 714 | 1974 | 4 | B3 | 0.01295 | Z2B | 1 | 6 | 17 | 96 |
| 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 | | 02 | 1928 | 130 | 1974 | 17 | B2 | 0.00330 | Z5B | 5 | 4 | 46 | 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 | 7 | B6 | 0.0 | Z9B | 2 | 0 | 32 | 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 | 237 | 0 |
| 01-148 | F | 1907 | | 06 | 1936 | 364 | 1958 | 40 | G4 | 0.0 | Z9 | 7 | 0 | 81 | 0 |
| 01-149 | F | 1888 | 1959 | 01 | 1919 | 26 | 1969 | 1630 | A1 | 0.00533 | A3 | 440 | 995 | 5226 | 14933 |
| 01-150 | F | 1881 | | 04 | 1930 | 104 | 1970 | 3 | B6 | 0.0 | Z9B | 1 | 0 | 10 | 0 |
| 01-151 | F | 1905 | | 06 | 1927 | 52 | 1976 | 1 | B6 | 0.0 | Z9 | 0 | 0 | 2 | 0 |
| 01-152 | F | 1904 | | 01 | 1920 | 17 | 1972 | 0 | B2 | 0.00290 | Z5B | 0 | 0 | 0 | 0 |
| 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 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-156 | 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 | 208 | 134 |
| 01-158 | F | 1901 | | 06 | 1920 | 52 | 1959 | 1 | G6 | 0.0 | Z9 | 0 | 0 | 4 | 0 |
| 01-159 | F | 1915 | | 01 | 1933 | 312 | 1972 | 2 | B6 | 0.0 | Z9B | 1 | 0 | 6 | 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 | 9 | 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 | 1974 | 13 | B2 | 0.0 | Z9C | 4 | 0 | 60 | 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 | 115 | 0 |
| 01-178 | M | 1939 | | 07 | 1958 | 0 | 1973 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 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 | 14 | 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 | 30 | 0 |
| 01-187 | M | 1917 | | 06 | 1943 | 78 | 1959 | 42 | B2 | 0.0 | Z9B | 7 | 0 | 51 | 0 |
| 01-188 | F | 1886 | | 04 | 1933 | 3 | 1959 | 4 | G6 | 0.0 | Z9 | 1 | 0 | 11 | 0 |
| 01-189 | M | 1921 | | 07 | 1958 | 0 | 1973 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 01-190 | F | 1927 | | 07 | 1958 | 0 | 1973 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 01-191 | M | 1897 | 1966 | 06 | 1913 | 78 | 1959 | 4 | B6 | 0.0 | Z9B | 1 | 0 | 12 | 0 |
| 01-192 | F | 1902 | 1962 | 01 | 1925 | 52 | 1959 | 34 | B2 | 0.0 | Z9B | 8 | 0 | 94 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-193 | F | 1886 | 1960 | 06 | 1917 | 156 | 1974 | 31 | A2 | 0.0 | Z9 | 9 | 0 | 105 | 0 |
| 01-194 | M | 1898 | | 01 | 1916 | 676 | 1972 | 7 | B6 | 0.0 | Z9B | 2 | 0 | 23 | 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 | 178 | 179 |
| 01-197 | F | 1883 | 1965 | 04 | 1916 | +0 | 1958 | 16 | G6 | 0.0 | Z9 | 4 | 0 | 61 | 0 |
| 01-200 | F | 1910 | | 01 | 1925 | 220 | 1959 | 0 | B6 | 0.08000 | Z2B | 0 | 0 | 0 | 0 |
| 01-201 | F | 1911 | | 01 | 1925 | 55 | 1959 | 26 | B2 | 0.02100 | Z8B | 6 | 8 | 89 | 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 | 21 | 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 | 32 | 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 | 1971 | 918 | B1 | 0.0 | Z9B | 171 | 0 | 982 | 0 |
| 01-209 | F | 1908 | 1975 | 01 | 1926 | 16 | 1959 | 6 | B6 | 0.02700 | Z8B | 1 | 2 | 20 | 32 |
| 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 | 15 | 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 | 24 | 27 |
| 01-229 | F | 1903 | | 01 | 1923 | 2 | 1959 | 8 | B2 | 0.08000 | Z2B | 2 | 13 | 29 | 196 |
| 01-230 | F | 1913 | | 01 | 1927 | 19 | 1973 | 1 | B6 | 0.00370 | Z8B | 0 | 0 | 4 | 4 |
| 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 | 3 | 19 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-236 | F | 1910 | | 01 | 1927 | 9 | 1965 | 1 | G6 | 0.01000 | Z8 | 0 | 0 | 4 | 4 |
| 01-237 | F | 1908 | | 01 | 1927 | 8 | 1975 | 0 | B6 | 0.00290 | 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 | D6 | 0.00450 | Z8D | 2 | 2 | 27 | 28 |
| 01-243 | M | 1873 | 1959 | 06 | 1905 | 520 | 1958 | 15 | G6 | 0.0 | Z9 | 4 | 0 | 43 | 0 |
| 01-244 | F | 1901 | | 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 | 639 | 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 | 103 | 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 | 110 | 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 | 1920 | | 06 | 1949 | 208 | 1959 | 14 | G6 | 0.0 | Z9 | 2 | 0 | 10 | 0 |
| 01-257 | M | 1885 | 1962 | 06 | 1941 | 624 | 1959 | 0 | G6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |
| 01-258 | M | 1903 | | 06 | 1923 | 1092 | 1969 | 17 | G6 | 0.0 | Z9 | 4 | 0 | 38 | 0 |
| 01-259 | F | 1910 | | 06 | 1927 | 416 | 1969 | 9 | G6 | 0.0 | Z9 | 2 | 0 | 31 | 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 | 103 | 0 |
| 01-263 | F | 1897 | 1976 | 01 | 1917 | 7 | 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 | 12 | 126 |
| 01-266 | F | 1904 | 1951 | 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 | 164 | 0 |
| 01-268 | F | 1901 | 1958 | 01 | 1920 | 48 | 1967 | 100 | B2 | 0.01000 | B2 | 29 | 84 | 391 | 1264 |
| 01-269 | M | 1911 | | 06 | 1932 | 52 | 1974 | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 01-270 | F | 1901 | | 01 | 1943 | 32 | 1976 | 4 | B3 | 0.0 | Z9 | 1 | 0 | 10 | 0 |
| 01-271 | F | 1900 | | 01 | 1917 | 86 | 1974 | 1 | B6 | 0.0 | Z9B | 0 | 0 | 5 | 0 |
| 01-272 | M | 1888 | | 06 | 1956 | 130 | 1959 | 78 | G6 | 0.0 | Z9 | 4 | 0 | 20 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-273 | F | 1907 | | 01 | 1924 | 1 | 1959 | 2 | B6 | 0.08400 | Z2B | 1 | 3 | 7 | 45 |
| 01-274 | F | 1906 | | 01 | 1922 | 5 | 1961 | 5 | B3 | 0.06200 | Z2B | 1 | 9 | 19 | 142 |
| 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 | 1976 | 0 | G6 | 0.01054 | Z2 | 0 | 0 | 0 | 0 |
| 01-278 | F | 1904 | | 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 | 15 | 100 |
| 01-287 | F | 1908 | | 01 | 1927 | 520 | 1960 | 7 | C6 | 0.01800 | Z8C | 2 | 1 | 20 | 12 |
| 01-288 | F | 1894 | 1970 | 01 | 1926 | 2 | 1960 | 2 | C6 | 0.02400 | Z8C | 1 | 1 | 6 | 11 |
| 01-289 | F | 1899 | | 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 | 1973 | 0 | B6 | 0.01470 | Z2B | 0 | 0 | 0 | 0 |
| 01-294 | F | 1912 | | 01 | 1927 | 52 | 1971 | 3 | B3 | 0.00450 | Z8B | 1 | 1 | 11 | 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 | 61 | 588 |
| 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 | 66 | 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 | 1966 | 160 | G4 | 0.0 | Z9C | 15 | 0 | 56 | 0 |
| 01-306 | M | 1928 | | 06 | 1955 | 364 | 1976 | 26 | B1 | 0.0 | Z9B | 5 | 0 | 23 | 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 |
| 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 | 3 | 3 |
| 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 | 9 | 0 |
| 01-314 | F | 1909 | | 01 | 1924 | 0 | 1961 | 1 | B6 | 0.06200 | Z2B | 0 | 1 | 4 | 22 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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) RA223 TO RA226 RATIO | (12) RA228 METHOD + ERR | (13) INPUT RA226 UCI | (14) INPUT RA228 UCI | (15) CUM RADS RA226 | (16) CUM RADS RA228 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-324 | F | 1907 | | 01 | 1923 | 15 | 1962 | 1 | G6 | 0.05700 | Z2 | 0 | 2 | 4 | 26 |
| 01-326 | F | 1896 | 1973 | 02 | 1925 | 156 | 1966 | 100 | G4 | 0.01100 | Z5 | 27 | 36 | 354 | 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 | 111 | 0 |
| 01-331 | M | 1901 | | 02 | 1927 | +0 | 1966 | 80 | G4 | 0.01100 | Z5 | 21 | 27 | 208 | 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 | 1975 | 3 | B3 | 0.0 | Z9B | 1 | 0 | 15 | 0 |
| 01-336 | M | 1899 | | 06 | 1945 | 1092 | 1976 | 39 | B1 | 0.0 | Z9B | 7 | 0 | 39 | 0 |
| 01-341 | M | 1883 | | 06 | 1943 | 176 | 1961 | 5 | B3 | 0.0 | Z9B | 1 | 0 | 6 | 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 | | 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 | 151 | 196 |
| 01-347 | M | 1896 | 1958 | 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 | 260 | 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 | | 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 | 90 | 460 |
| 01-360 | F | 1911 | | 01 | 1928 | 34 | 1962 | 0 | G6 | 0.01400 | Z8 | 0 | 0 | 0 | 0 |
| 01-361 | F | 1907 | | 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 | | 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 | 19 | 13 |
| 01-365 | F | 1901 | | 01 | 1924 | 40 | 1962 | 10 | G6 | 0.05700 | Z2 | 3 | 15 | 37 | 218 |
| 01-367 | F | 1899 | | 01 | 1920 | 221 | 1976 | 4 | B6 | 0.01024 | Z2B | 1 | 9 | 18 | 135 |
| 01-368 | M | 1925 | | 06 | 1947 | 65 | 1976 | 28 | B2 | 0.0 | Z9B | 6 | 0 | 43 | 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 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-371 | F | 1912 | | 07 | 1928 | 36 | 1962 | 0 | G6 | 0.01400 | Z8 | 0 | 0 | 0 | 0 |
| 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 | 41 | 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 | 1975 | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 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 | 75 | 88 |
| 01-380 | F | 1910 | | 01 | 1927 | 3 | 1972 | 0 | B6 | 0.00420 | Z8B | 0 | 0 | 0 | 0 |
| 01-381 | M | 1887 | | 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 | 167 | 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 | 31 | 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 | 5 | 0 |
| 01-395 | F | 1945 | | 07 | 1950 | 520 | 1972 | 5 | B3 | 0.0 | Z9B | 1 | 0 | 7 | 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 |
| 01-403 | F | 1912 | | 02 | 1926 | +0 | 1971 | 27 | B2 | 0.01838 | C3 | 8 | 34 | 108 | 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 | | 67 | 1930 | 416 | 1963 | 38 | B2 | 0.0 | Z9B | 9 | 0 | 76 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-408 | F | 1918 | | 06 | 1934 | 415 | 1975 | 13 | B2 | 0.0 | Z9B | 3 | 0 | 39 | 0 |
| 01-409 | F | 1914 | | 06 | 1930 | 13 | 1975 | 34 | B3 | 0.0 | Z9B | 10 | 0 | 127 | 0 |
| 01-410 | F | 1920 | | 06 | 1940 | 156 | 1975 | 33 | B1 | 0.0 | Z9B | 8 | 0 | 88 | 0 |
| 01-411 | M | 1915 | | 06 | 1935 | 200 | 1973 | 8 | B2 | 0.0 | Z9C | 2 | 0 | 17 | 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 | 572 | 1974 | 1 | B6 | 0.0 | Z9B | 0 | 0 | 3 | 0 |
| 01-415 | M | 1898 | | 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 | 34 | 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 | 1888 | | 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 | 71 | 0 |
| 01-424 | F | 1882 | | 05 | 1924 | +0 | 1964 | 280 | G4 | 0.0 | Z9 | 76 | 0 | 1074 | 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 | 1974 | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 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 | 1974 | 06 | 1915 | 520 | 1964 | 17 | B2 | 0.0 | Z9B | 5 | 0 | 50 | 0 |
| 01-434 | M | 1880 | 1932 | 02 | 1927 | 156 | 1965 | 6126 | A1 | 0.02139 | A1 | 456 | 828 | 865 | 3250 |
| 01-435 | F | 1907 | | 01 | 1925 | 5 | 1974 | 4 | B3 | 0.00327 | Z8B | 1 | 2 | 17 | 23 |
| 01-436 | F | 1895 | | 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 | 1650 | A1 | 0.01372 | A1 | 279 | 382 | 1163 | 3571 |
| 01-439 | F | 1880 | 1953 | 04 | 1922 | 8 | 1968 | 406 | A2 | 0.0 | Z9F | 96 | 0 | 971 | 0 |
| 01-440 | F | 1908 | | 01 | 1924 | 204 | 1965 | 0 | G6 | 0.03900 | Z2 | 0 | 0 | 0 | 0 |
| 01-446 | F | 1907 | | 01 | 1925 | 0 | 1964 | 0 | G6 | 0.04400 | Z2 | 0 | 0 | 0 | 0 |
| 01-447 | F | 1909 | | 17 | 1925 | 110 | 1965 | 3 | G6 | 0.01000 | Z8 | 1 | 1 | 11 | 14 |
| 01-448 | F | 1907 | | 01 | 1925 | 5 | 1964 | 25 | G4 | 0.01140 | Z8 | 7 | 9 | 93 | 131 |
| 01-449 | F | 1899 | | 01 | 1922 | 2 | 1965 | 7 | G6 | 0.03900 | Z2 | 2 | 14 | 29 | 215 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-450 | M | 1877 | 1936 | 06 | 1912 | 364 | 1966 | 0 | A6 | 0.0 | Z9A | 0 | 0 | 0 | 0 |
| 01-454 | F | 1880 | 1970 | 01 | 1920 | 884 | 1974 | 1910 | A1 | 0.0 | | 563 | 0 | 7448 | 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 | 33 | 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 | 15 | 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 | 1965 | 0 | G6 | 0.01000 | 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 | 1974 | 0 | B6 | 0.01163 | Z2B | 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 | 15 | 16 |
| 01-477 | F | 1897 | | 02 | 1925 | +0 | 1965 | 1240 | B1 | 0.00475 | B2 | 336 | 207 | 4694 | 3111 |
| 01-478 | F | 1914 | | 01 | 1935 | 24 | 1965 | 0 | G6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |
| 01-479 | F | 1912 | | 01 | 1927 | 1 | 1965 | 3 | G6 | 0.01000 | Z8 | 1 | 1 | 11 | 12 |
| 01-480 | F | 1915 | | 01 | 1927 | 1 | 1965 | 38 | G6 | 0.01000 | Z8 | 10 | 10 | 136 | 153 |
| 01-481 | F | 1909 | | 01 | 1927 | 14 | 1965 | 0 | G6 | 0.01000 | Z8 | 0 | 0 | 0 | 0 |
| 01-482 | F | 1912 | | 01 | 1927 | 4 | 1974 | 1 | B6 | 0.00330 | Z8B | 0 | 0 | 4 | 4 |
| 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 | 756 | 637 |
| 01-490 | F | 1908 | | 01 | 1924 | 17 | 1974 | 2 | B6 | 0.01318 | Z2B | 1 | 3 | 9 | 52 |
| 01-491 | F | 1922 | 1966 | 01 | 1943 | 728 | 1963 | 7 | G6 | 0.0 | Z9 | 1 | 0 | 7 | 0 |
| 01-492 | F | 1900 | | 06 | 1921 | 260 | 1973 | 1 | B6 | 0.0 | Z9B | 0 | 0 | 4 | 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 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-497 | F | 1902 | | 01 | 1921 | 8 | 1966 | 13 | G6 | 0.03400 | Z2 | 4 | 30 | 55 | 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 | 33 | 37 |
| 01-506 | F | 1897 | | 04 | 1923 | 4 | 1966 | 7 | B3 | 0.0 | Z9C | 2 | 0 | 28 | 0 |
| 01-507 | F | 1909 | | 01 | 1927 | 22 | 1974 | 8 | B2 | 0.00313 | Z8B | 2 | 2 | 32 | 33 |
| 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 | 138 | 152 |
| 01-511 | F | 1908 | | 07 | 1927 | 9 | 1974 | 0 | B6 | 0.00330 | 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 | | 05 | 1940 | 0 | 1965 | 4 | G6 | 0.0 | Z9 | 1 | 0 | 10 | 0 |
| 01-516 | F | 1907 | | 01 | 1927 | 2 | 1967 | 7 | G6 | 0.00780 | Z8 | 2 | 2 | 26 | 29 |
| 01-518 | M | 1912 | | 05 | 1949 | +0 | 1966 | 15 | G4 | 0.0 | Z9 | 3 | 0 | 17 | 0 |
| 01-519 | M | 1919 | | 06 | 1937 | 260 | 1967 | 13 | G6 | 0.0 | Z9 | 3 | 0 | 23 | 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 | 1976 | 26 | B1 | 0.0 | Z9B | 6 | 0 | 41 | 0 |
| 01-522 | M | 1905 | | 06 | 1928 | 1924 | 1969 | 240 | B1 | 0.0 | Z9B | 42 | 0 | 292 | 0 |
| 01-523 | M | 1917 | | 06 | 1942 | 312 | 1968 | 30 | G4 | 0.0 | Z9 | 6 | 0 | 44 | 0 |
| 01-525 | M | 1923 | | 06 | 1943 | 104 | 1968 | 17 | G6 | 0.0 | Z9 | 4 | 0 | 26 | 0 |
| 01-526 | M | 1921 | | 06 | 1945 | 38 | 1976 | 35 | B1 | 0.0 | Z9B | 8 | 0 | 59 | 0 |
| 01-529 | M | 1920 | | 06 | 1943 | 260 | 1975 | 14 | B2 | 0.0 | Z9B | 3 | 0 | 23 | 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 | 22 | 0 |
| 01-532 | M | 1914 | 1973 | 06 | 1945 | 133 | 1968 | 1 | G6 | 0.0 | Z9 | 0 | 0 | 1 | 0 |
| 01-533 | F | 1903 | | 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 | 24 | 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 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (1) CASE | (2) SEX | (3) ECRN | (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-546 | F | 1897 | | 01 | 1914 | 52 | 1967 | 0 | G6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |
| 01-547 | F | 1897 | | 06 | 1920 | 104 | 1975 | 4 | B3 | 0.0 | Z9B | 1 | 0 | 19 | 0 |
| 01-548 | M | 1917 | | 02 | 1930 | +0 | 1972 | 5 | B3 | 0.00200 | Z5B | 1 | 0 | 13 | 5 |
| 01-552 | M | 1907 | | 06 | 1936 | 104 | 1967 | 20 | G4 | 0.0 | Z9 | 5 | 0 | 39 | 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 | 257 | 0 |
| 01-555 | F | 1894 | | 01 | 1921 | 2 | 1975 | 0 | B6 | 0.01155 | Z2B | 0 | 0 | 0 | 0 |
| 01-556 | F | 1910 | | 01 | 1927 | 0 | 1967 | 0 | G6 | 0.00780 | Z8 | 0 | 0 | 0 | 0 |
| 01-557 | F | 1908 | | 01 | 1925 | 35 | 1975 | 2 | B6 | 0.00293 | Z8B | 1 | 1 | 8 | 11 |
| 01-558 | M | 1913 | | 02 | 1927 | 130 | 1976 | 255 | B1 | 0.00077 | B2 | 76 | 19 | 724 | 206 |
| 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 | 195 | 0 | 183 | 0 |
| 01-570 | F | 1908 | | 01 | 1926 | 260 | 1968 | 10 | G4 | 0.0 | Z9 | 3 | 0 | 36 | 0 |
| 01-571 | F | 1911 | | 01 | 1928 | 44 | 1968 | 1 | B6 | 0.00680 | Z8B | 0 | 0 | 4 | 3 |
| 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 | | 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 | 202 | 0 |
| 01-578 | F | 1904 | 1930 | 05 | 1926 | 17 | 1968 | 2000 | A2 | 0.0 | Z9A | 160 | 0 | 452 | 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 | 14 | 0 |
| 01-582 | F | 1893 | | 06 | 1917 | 24 | 1974 | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 01-583 | M | 1890 | 1969 | 06 | 1918 | 104 | 1968 | 0 | G6 | 0.00250 | Z7 | 0 | 0 | 0 | 0 |
| 01-584 | F | 1908 | 1975 | 01 | 1926 | 260 | 1968 | 10 | B2 | 0.0 | Z9B | 3 | 0 | 35 | 0 |
| 01-585 | F | 1906 | 1969 | 01 | 1925 | 26 | 1968 | 0 | B6 | 0.00450 | Z5B | 0 | 0 | 0 | 0 |
| 01-586 | F | 1879 | 1973 | 05 | 1924 | +0 | 1968 | 130 | G6 | 0.0 | Z9 | 37 | 0 | 504 | 0 |
| 01-588 | F | 1908 | | 01 | 1929 | 104 | 1968 | 5 | G6 | 0.0 | Z9 | 1 | 0 | 17 | 0 |
| 01-589 | M | 1907 | | 06 | 1927 | 78 | 1964 | 2 | G6 | 0.0 | Z9 | 1 | 0 | 5 | 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 | 1 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-595 | F | 1897 | | 01 | 1917 | 130 | 1969 | 5 | G6 | 0.0 | Z9 | 2 | 0 | 23 | 0 |
| 01-597 | F | 1923 | | 01 | 1940 | 364 | 1973 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 01-598 | M | 1879 | 1953 | 06 | 1947 | +0 | 1952 | 400 | G6 | 0.0 | Z9 | 55 | 0 | 220 | 0 |
| 01-599 | F | 1909 | | 01 | 1927 | 7 | 1973 | 2 | B6 | 0.00370 | Z8B | 1 | 1 | 8 | 9 |
| 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 | 31 | 41 |
| 01-604 | F | 1896 | | 01 | 1918 | 52 | 1971 | 1 | B6 | 0.0 | Z9B | 0 | 0 | 5 | 0 |
| 01-608 | F | 1906 | | 01 | 1927 | 11 | 1974 | 0 | G6 | 0.00330 | Z8B | 0 | 0 | 0 | 0 |
| 01-609 | F | 1906 | | 01 | 1926 | 366 | 1973 | 3 | B6 | 0.0 | Z9B | 1 | 0 | 11 | 0 |
| 01-610 | M | 1904 | 1969 | 06 | 1919 | 208 | 1968 | 10 | G6 | 0.00450 | Z7 | 3 | 4 | 28 | 43 |
| 01-612 | F | 1859 | 1936 | 01 | 1923 | 255 | 1972 | 18 | A1 | 0.00680 | Z4A | 3 | 6 | 14 | 71 |
| 01-613 | F | 1906 | 1936 | 67 | 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 | 4 | B3 | 0.00020 | Z3B | 1 | 0 | 13 | 1 |
| 01-619 | F | 1909 | | 01 | 1927 | 52 | 1969 | 0 | G6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |
| 01-621 | F | 1908 | | 01 | 1924 | 2 | 1975 | 7 | B2 | 0.01135 | Z2B | 2 | 12 | 30 | 181 |
| 01-625 | F | 1911 | | 01 | 1927 | 468 | 1968 | 6 | G6 | 0.0 | Z9 | 2 | 0 | 20 | 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 | | 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 |
| 01-640 | F | 1908 | | 01 | 1928 | 21 | 1969 | 34 | G6 | 0.00420 | Z5 | 10 | 10 | 138 | 143 |
| 01-653 | F | 1910 | | 01 | 1925 | 78 | 1969 | 7 | G6 | 0.00420 | Z5 | 2 | 2 | 28 | 25 |
| 01-659 | F | 1912 | | 01 | 1928 | 26 | 1969 | 11 | G6 | 0.0 | Z9 | 3 | 0 | 40 | 0 |
| 01-660 | F | 1881 | 1937 | 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 | 29 | 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 | 104 | 1969 | 0 | G6 | 0.0 | Z9 | 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 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-674 | M | 1908 | | 01 | 1931 | 1716 | 1973 | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 01-681 | F | 1904 | | 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 | 1975 | 0 | B6 | 0.01149 | Z2 | 0 | 0 | 0 | 0 |
| 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 | 1970 | 0 | G6 | 0.00370 | 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 | 1974 | 4 | B6 | 0.00420 | Z5 | 1 | 1 | 11 | 16 |
| 01-728 | F | 1912 | | 01 | 1927 | 6 | 1973 | 3 | B3 | 0.00370 | Z8B | 1 | 1 | 12 | 13 |
| 01-739 | F | 1856 | 1928 | 05 | 1926 | 7 | 1972 | 11500 | A1 | 0.0 | Z9A | 645 | 0 | 1226 | 0 |
| 03-005 | M | 1917 | | 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 | | 05 | 1931 | 15 | 1973 | 628 | B1 | 0.0 | Z9C | 174 | 0 | 1598 | 0 |
| 03-103 | F | 1868 | 1952 | 05 | 1931 | 15 | 1951 | 420 | E4 | 0.0 | Z9 | 79 | 0 | 621 | 0 |
| 03-104 | F | 1880 | 1945 | 05 | 1931 | 15 | 1931 | 13900 | E4 | 0.0 | Z9 | 449 | 0 | 2727 | 0 |
| 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 | 69 | 0 | 558 | 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 | 3128 | 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 | 1300 | E4 | 0.0 | Z9 | 39 | 0 | 244 | 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 | 2647 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 03-116 | F | 1907 | | 05 | 1931 | 25 | 1973 | 1411 | B1 | 0.0 | Z9C | 391 | 0 | 5015 | 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 | 4[illegible] | 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 | 1[illegible] | 1932 | 5300 | E4 | 0.0 | Z9 | 199 | 0 | 721 | 0 |
| 03-121 | F | 1911 | 1972 | 05 | 1931 | [illegible]9 | 1964 | 371 | B1 | 0.0 | Z9 | 91 | 0 | 1099 | 0 |
| 03-122 | M | 1908 | 1942 | 05 | 1931 | 1C | 1931 | 6500 | E4 | 0.0 | Z9 | 92 | 0 | 345 | 0 |
| 03-123 | M | 1914 | 1937 | 05 | 1931 | 9 | 1931 | 9700 | B2 | 0.0 | Z9 | 139 | 0 | 361 | 0 |
| 03-124 | M | 1910 | 1942 | 05 | 1931 | 9 | 1931 | 4200 | B2 | 0.0 | Z9 | 60 | 0 | 226 | 0 |
| 03-125 | F | 1913 | | 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 | 1712 | 0 |
| 03-135 | M | 1905 | | 05 | 1931 | +0 | 1973 | 1431 | B1 | 0.0 | Z9C | 398 | 0 | 3656 | 0 |
| 03-139 | M | 1908 | | 05 | 1933 | 11 | 1973 | 373 | C2 | 0.0 | Z9C | 101 | 0 | 899 | 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 | 4541 | 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 | | 05 | 1929 | 15 | 1968 | 291 | C2 | 0.0 | Z9 | 78 | 0 | 1026 | 0 |
| 03-206 | M | 1914 | 1975 | 05 | 1936 | 4 | 1973 | 3297 | B1 | 0.0 | Z9C | 858 | 0 | 7176 | 0 |
| 03-207 | F | 1879 | 1969 | 04 | 1922 | 416 | 1960 | 755 | C2 | 0.0 | Z9 | 188 | 0 | 2344 | 0 |
| 03-209 | M | 1894 | 1960 | 05 | 1925 | 572 | 1973 | 1105 | A1 | 0.0 | Z9A | 254 | 0 | 1776 | 0 |
| 03-210 | M | 1906 | 1958 | 05 | 1926 | +0 | 1957 | 1350 | C2 | 0.00089 | F2 | 321 | 12 | 2360 | 132 |
| 03-211 | M | 1890 | | 05 | 1923 | 20 | 1960 | 10 | C3 | 0.0 | Z9 | 3 | 0 | 26 | 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 | 196[illegible] | 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 | 352 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 03-221 | 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 | 1973 | 33 | B1 | 0.0 | Z9C | 9 | 0 | 88 | 0 |
| 03-226 | M | 1874 | 1953 | 05 | 1934 | 39 | 1951 | 10700 | B2 | 0.0 | Z9 | 1837 | 0 | 9588 | 0 |
| 03-227 | F | 1878 | 1952 | 05 | 1930 | +0 | 1952 | 1000 | B2 | 0.0 | Z9 | 199 | 0 | 1612 | 0 |
| 03-228 | M | 1900 | 1955 | 05 | 1927 | +0 | 1951 | 5600 | B2 | 0.0 | Z9 | 1164 | 0 | 7866 | 0 |
| 03-230 | F | 1899 | | 05 | 1927 | +0 | 1976 | 438 | B1 | 0.0 | Z9C | 132 | 0 | 1793 | 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 | 5205 | 220 |
| 03-403 | F | 1915 | 1964 | 01 | 1935 | 572 | 1957 | 8 | C3 | 0.0 | Z9 | 1 | 0 | 11 | 0 |
| 03-404 | F | 1897 | | 01 | 1923 | 195 | 1975 | 577 | B1 | 0.0 | Z9C | 177 | 0 | 2481 | 0 |
| 03-405 | F | 1904 | | 16 | 1924 | 273 | 1962 | 625 | C2 | 0.0 | Z9 | 159 | 0 | 2171 | 0 |
| 03-406 | F | 1914 | | 01 | 1935 | 481 | 1972 | 7 | B3 | 0.0 | Z9C | 2 | 0 | 19 | 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 | 20 | 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 | 4 | 0 |
| 03-412 | F | 1894 | | 01 | 1922 | 134 | 1975 | 180 | B1 | 0.0 | Z9C | 56 | 0 | 796 | 0 |
| 03-413 | F | 1917 | | 01 | 1939 | 169 | 1972 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 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 | 1976 | 1033 | B1 | 0.0 | Z9C | 322 | 0 | 4580 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 03-417 | F | 1909 | 1966 | 01 | 1924 | 60 | 1964 | 617 | C2 | 0.0 | Z9 | 166 | 0 | 2023 | 0 |
| 03-418 | F | 1896 | | 61 | 1926 | 602 | 1972 | 4 | B3 | 0.0 | Z9C | 1 | 0 | 13 | 0 |
| 03-419 | F | 1906 | | 01 | 1924 | 208 | 1962 | 679 | C2 | 0.0 | Z9 | 177 | 0 | 2468 | 0 |
| 03-420 | F | 1906 | 1960 | 01 | 1922 | 212 | 1957 | 18 | C2 | 0.0 | Z9 | 4 | 0 | 49 | 0 |
| 03-421 | F | 1908 | | 01 | 1924 | 117 | 1974 | 5 | B3 | 0.0 | Z9C | 2 | 0 | 21 | 0 |
| 03-422 | F | 1907 | | 06 | 1925 | 104 | 1975 | 11 | B2 | 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 | 185 | 1976 | 277 | B2 | 0.0 | Z9C | 86 | 0 | 1203 | 0 |
| 03-425 | F | 1916 | | 01 | 1935 | 260 | 1973 | 2 | B6 | 0.0 | Z9C | 1 | 0 | 6 | 0 |
| 03-426 | F | 1906 | | 01 | 1924 | 2184 | 1972 | 139 | B1 | 0.0 | Z9C | 41 | 0 | 572 | 0 |
| 03-427 | F | 1906 | | 01 | 1925 | 823 | 1973 | 12 | B2 | 0.0 | Z9C | 4 | 0 | 51 | 0 |
| 03-428 | F | 1908 | | 01 | 1925 | 164 | 1974 | 493 | B1 | 0.0 | Z9C | 148 | 0 | 2048 | 0 |
| 03-429 | F | 1908 | 1976 | 01 | 1923 | 203 | 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 | 9 | 0 |
| 03-431 | F | 1901 | | 01 | 1922 | 156 | 1963 | 1297 | C2 | 0.0 | Z9 | 349 | 0 | 4970 | 0 |
| 03-432 | F | 1902 | | 01 | 1923 | 112 | 1974 | 25 | B2 | 0.0 | Z9C | 8 | 0 | 107 | 0 |
| 03-433 | F | 1904 | | 01 | 1924 | 117 | 1964 | 1052 | C2 | 0.0 | Z9 | 281 | 0 | 3930 | 0 |
| 03-434 | F | 1920 | | 01 | 1941 | 125 | 1975 | 5 | B2 | 0.0 | Z9C | 1 | 0 | 13 | 0 |
| 03-435 | F | 1912 | | 01 | 1935 | 104 | 1971 | 3 | B6 | 0.0 | Z9C | 1 | 0 | 8 | 0 |
| 03-436 | F | 1910 | | 01 | 1926 | 619 | 1975 | 8 | B3 | 0.0 | Z9C | 2 | 0 | 30 | 0 |
| 03-437 | F | 1906 | | 01 | 1926 | 52 | 1957 | 55 | C2 | 0.0 | Z9 | 13 | 0 | 177 | 0 |
| 03-438 | F | 1908 | | 01 | 1925 | 8 | 1957 | 0 | C6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |
| 03-439 | F | 1906 | | 01 | 1925 | 56 | 1957 | 0 | C6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |
| 03-440 | F | 1908 | | 01 | 1925 | 3 | 1974 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 4 | 0 |
| 03-441 | F | 1905 | | 01 | 1925 | 528 | 1957 | 56 | C2 | 0.0 | Z9 | 13 | 0 | 186 | 0 |
| 03-442 | F | 1904 | | 01 | 1924 | 13 | 1976 | 4 | B2 | 0.0 | Z9 | 1 | 0 | 17 | 0 |
| 03-443 | F | 1914 | | 01 | 1935 | 316 | 1971 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 03-444 | F | 1907 | | 01 | 1925 | 56 | 1974 | 12 | B2 | 0.0 | Z9C | 3 | 0 | 48 | 0 |
| 03-445 | F | 1905 | 1974 | 01 | 1922 | 260 | 1966 | 1367 | C2 | 0.0 | Z9 | 380 | 0 | 5237 | 0 |
| 03-446 | F | 1903 | | 01 | 1921 | 260 | 1974 | 48 | B1 | 0.0 | Z9C | 15 | 0 | 207 | 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 | 1974 | 8 | B2 | 0.0 | Z9C | 2 | 0 | 33 | 0 |
| 03-451 | F | 1922 | | 01 | 1940 | 524 | 1972 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 03-452 | F | 1909 | | 16 | 1925 | 728 | 1974 | 15 | B1 | 0.0 | Z9C | 4 | 0 | 54 | 0 |
| 03-453 | F | 1907 | | 01 | 1924 | 8 | 1976 | 3 | B2 | 0.0 | Z9C | 1 | 0 | 13 | 0 |
| 03-454 | F | 1914 | | 06 | 1934 | 572 | 1958 | 48 | C2 | 0.0 | Z9 | 9 | 0 | 97 | 0 |
| 03-455 | F | 1906 | | 01 | 1922 | 56 | 1975 | 491 | B1 | 0.00054 | F1 | 153 | 49 | 2206 | 737 |
| 03-456 | F | 1921 | 1965 | 01 | 1943 | 416 | 1958 | 33 | C2 | 0.0 | Z9 | 4 | 0 | 32 | 0 |
| 03-457 | F | 1915 | | 01 | 1939 | 520 | 1972 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 03-458 | F | 1925 | | 01 | 1945 | 1560 | 1976 | 33 | B2 | 0.0 | Z9C | 4 | 0 | 23 | 0 |
| 03-459 | F | 1906 | | 01 | 1924 | 43 | 1976 | 774 | B1 | 0.0 | Z9C | 239 | 0 | 3367 | 0 |
| 03-460 | F | 1905 | | 01 | 1923 | 19 | 1972 | 2 | B6 | 0.0 | Z9C | 1 | 0 | 10 | 0 |
| 03-461 | F | 1896 | | 01 | 1922 | 6 | 1958 | 6 | C3 | 0.0 | Z9 | 2 | 0 | 22 | 0 |
| 03-462 | F | 1906 | | 01 | 1922 | 2756 | 1975 | 240 | B1 | 0.0 | Z9C | 74 | 0 | 1044 | 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 | 21 | 0 |
| 03-466 | F | 1904 | | 01 | 1924 | 10 | 1976 | 2 | B3 | 0.0 | Z9C | 1 | 0 | 7 | 0 |
| 03-467 | F | 1911 | | 01 | 1926 | 416 | 1976 | 8 | B2 | 0.0 | Z9C | 2 | 0 | 29 | 0 |
| 03-468 | F | 1908 | | 01 | 1926 | 121 | 1958 | 29 | C2 | 0.0 | Z9 | 7 | 0 | 93 | 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 | 7 | 0 |
| 03-471 | F | 1908 | | 01 | 1926 | 91 | 1958 | 13 | C3 | 0.0 | Z9 | 3 | 0 | 42 | 0 |
| 03-472 | F | 1922 | | 01 | 1941 | 247 | 1972 | 5 | B3 | 0.0 | Z9C | 1 | 0 | 13 | 0 |
| 03-473 | F | 1904 | 1965 | 01 | 1922 | 156 | 1962 | 1170 | C2 | 0.0 | Z9 | 311 | 0 | 3793 | 0 |
| 03-474 | F | 1909 | | 01 | 1925 | 21 | 1958 | 19 | C2 | 0.0 | Z9 | 5 | 0 | 65 | 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 | 12 | 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 | 1975 | 27 | B1 | 0.00017 | F2 | 8 | 1 | 115 | 10 |
| 03-480 | F | 1909 | | 01 | 1924 | 10 | 1975 | 2 | B3 | 0.0 | Z9 | 1 | 0 | 9 | 0 |
| 03-481 | F | 1922 | | 01 | 1942 | 481 | 1972 | 9 | B2 | 0.0 | Z9C | 2 | 0 | 18 | 0 |
| 03-482 | F | 1927 | | 01 | 1944 | 130 | 1972 | 3 | B6 | 0.0 | Z9C | 1 | 0 | 6 | 0 |
| 03-483 | F | 1901 | | 01 | 1922 | 177 | 1975 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 4 | 0 |
| 03-484 | F | 1888 | 1966 | 01 | 1919 | 156 | 1962 | 1622 | C2 | 0.0 | Z9 | 448 | 0 | 5807 | 0 |
| 03-485 | F | 1909 | | 01 | 1929 | 364 | 1958 | 0 | C6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |
| 03-486 | F | 1909 | | 01 | 1925 | 156 | 1966 | 267 | C2 | 0.0 | Z9 | 73 | 0 | 1011 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (1) CASE | (2) SEX | (3) BCRN | (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 03-487 | 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 | 13 | 0 |
| 03-491 | F | 1908 | | 01 | 1924 | 2 | 1976 | 34 | B1 | 0.0 | Z9C | 10 | 0 | 148 | 0 |
| 03-492 | F | 1928 | | 01 | 1946 | 325 | 1973 | 5 | B3 | 0.0 | Z9C | 1 | 0 | 9 | 0 |
| 03-493 | F | 1893 | | 01 | 1920 | 139 | 1975 | 6 | B3 | 0.0 | Z9C | 2 | 0 | 25 | 0 |
| 03-494 | F | 1902 | | 01 | 1924 | 177 | 1959 | 4 | C3 | 0.0 | Z9 | 1 | 0 | 14 | 0 |
| 03-495 | F | 1910 | | 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 | 6 | 0 |
| 03-499 | F | 1905 | | 01 | 1924 | 56 | 1976 | 219 | B1 | 0.00223 | C3 | 68 | 79 | 950 | 1182 |
| 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 | 22 | 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 | 1974 | 9 | B2 | 0.0 | Z9C | 3 | 0 | 40 | 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 | 13 | 0 |
| 03-507 | F | 1907 | 1962 | 01 | 1923 | 6 | 1959 | 12 | C3 | 0.0 | Z9 | 3 | 0 | 36 | 0 |
| 03-508 | F | 1905 | 1963 | 01 | 1923 | 8 | 1959 | 10 | C3 | 0.0 | Z9 | 3 | 0 | 31 | 0 |
| 03-509 | F | 1907 | | 01 | 1924 | 2548 | 1973 | 28 | B1 | 0.0 | Z9C | 8 | 0 | 115 | 0 |
| 03-510 | F | 1907 | | 01 | 1923 | 2028 | 1962 | 729 | C2 | 0.0 | Z9 | 191 | 0 | 2685 | 0 |
| 03-511 | F | 1910 | | 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 | 38 | 0 |
| 03-513 | F | 1908 | | 01 | 1925 | 48 | 1974 | 73 | B1 | 0.0 | Z9 | 22 | 0 | 305 | 0 |
| 03-514 | F | 1909 | | 01 | 1925 | 208 | 1959 | 26 | C2 | 0.0 | Z9 | 6 | 0 | 89 | 0 |
| 03-515 | F | 1908 | | 01 | 1925 | 156 | 1959 | 11 | C3 | 0.0 | Z9 | 3 | 0 | 38 | 0 |
| 03-516 | F | 1911 | | 01 | 1925 | 624 | 1976 | 7 | B2 | 0.0 | Z9C | 2 | 0 | 31 | 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 | 17 | 0 |
| 03-519 | F | 1903 | | 01 | 1924 | 8 | 1959 | 98 | C2 | 0.0 | Z9 | 25 | 0 | 350 | 0 |
| 03-520 | F | 1907 | | 01 | 1925 | 780 | 1974 | 112 | C2 | 0.0 | Z9 | 33 | 0 | 464 | 0 |
| 03-521 | F | 1907 | 1961 | 01 | 1925 | 39 | 1959 | 10 | C3 | 0.0 | Z9 | 2 | 0 | 27 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (1) CASE | (2) SEX | (3) ECRN | (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 03-522 | F | 1898 | | 01 | 1921 | 52 | 1976 | 148 | B2 | 0.0 | Z9C | 47 | 0 | 686 | 0 |
| 03-523 | F | 1900 | | 01 | 1923 | 30 | 1972 | 15 | B2 | 0.0 | Z9C | 4 | 0 | 63 | 0 |
| 03-524 | F | 1903 | | 01 | 1925 | 260 | 1972 | 48 | B2 | 0.0 | Z9C | 14 | 0 | 194 | 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 | 17 | 0 |
| 03-528 | F | 1904 | | 01 | 1922 | 524 | 1959 | 1630 | C2 | 0.0 | Z9 | 412 | 0 | 5827 | 0 |
| 03-529 | F | 1902 | | 01 | 1921 | 104 | 1974 | 72 | B6 | 0.0 | Z9C | 22 | 0 | 326 | 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 | 141 | 0 |
| 03-532 | F | 1910 | | 01 | 1926 | 190 | 1974 | 56 | B2 | 0.0 | Z9C | 16 | 0 | 218 | 0 |
| 03-533 | F | 1908 | | 01 | 1925 | 260 | 1974 | 15 | B1 | 0.0 | Z9C | 4 | 0 | 60 | 0 |
| 03-534 | F | 1910 | | 01 | 1925 | 104 | 1976 | 3 | B3 | 0.0 | Z9 | 1 | 0 | 14 | 0 |
| 03-535 | F | 1907 | | 01 | 1922 | 21 | 1964 | 227 | C2 | 0.0 | Z9 | 63 | 0 | 911 | 0 |
| 03-536 | F | 1910 | | 01 | 1925 | 7 | 1959 | 35 | C2 | 0.0 | Z9 | 9 | 0 | 122 | 0 |
| 03-537 | F | 1900 | | 07 | 1916 | 52 | 1972 | 6 | B3 | 0.0 | Z9C | 2 | 0 | 30 | 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 | 1974 | 5 | B2 | 0.0 | Z9C | 2 | 0 | 24 | 0 |
| 03-540 | F | 1904 | | 01 | 1923 | 364 | 1973 | 1605 | B1 | 0.0 | Z9C | 481 | 0 | 6758 | 0 |
| 03-541 | F | 1913 | | 01 | 1935 | 156 | 1973 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 03-542 | F | 1904 | | 01 | 1924 | 13 | 1974 | 24 | B1 | 0.0 | Z9C | 7 | 0 | 103 | 0 |
| 03-543 | F | 1918 | | 01 | 1947 | 100 | 1972 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 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 | 326 | 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 | 348 | 0 |
| 03-549 | F | 1910 | | 01 | 1925 | 936 | 1974 | 36 | B1 | 0.0 | Z9C | 11 | 0 | 151 | 0 |
| 03-550 | F | 1900 | | 01 | 1917 | 104 | 1972 | 8 | B3 | 0.0 | Z9C | 2 | 0 | 38 | 0 |
| 03-551 | F | 1903 | | 01 | 1922 | 338 | 1973 | 1077 | C2 | 0.0 | Z9C | 324 | 0 | 4588 | 0 |
| 03-552 | F | 1904 | | 01 | 1924 | 108 | 1972 | 123 | B1 | 0.0 | Z9C | 36 | 0 | 506 | 0 |
| 03-553 | F | 1904 | | 01 | 1924 | 13 | 1974 | 5 | B2 | 0.0 | Z9C | 2 | 0 | 23 | 0 |
| 03-554 | F | 1899 | | 01 | 1924 | 433 | 1961 | 2000 | G4 | 0.0 | Z9 | 513 | 0 | 7167 | 0 |
| 03-555 | F | 1913 | | 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 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 03-557 | F | 1910 | | 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 | 233 | 0 |
| 03-562 | F | 1908 | | 01 | 1927 | 520 | 1972 | 4 | B3 | 0.0 | Z9C | 1 | 0 | 12 | 0 |
| 03-563 | F | 1909 | | 01 | 1924 | 10 | 1975 | 2 | B3 | 0.0 | Z9C | 1 | 0 | 10 | 0 |
| 03-564 | F | 1906 | | 01 | 1923 | 3 | 1976 | 3 | B2 | 0.0 | Z9C | 1 | 0 | 15 | 0 |
| 03-565 | F | 1913 | | 01 | 1930 | 676 | 1972 | 5 | B3 | 0.0 | Z9C | 1 | 0 | 16 | 0 |
| 03-566 | F | 1910 | | 01 | 1930 | 624 | 1972 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 03-567 | F | 1900 | | 01 | 1922 | 104 | 1972 | 26 | B2 | 0.0 | Z9C | 8 | 0 | 110 | 0 |
| 03-568 | F | 1905 | | 01 | 1922 | 260 | 1959 | 120 | C2 | 0.0 | Z9 | 30 | 0 | 429 | 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 | 35 | 0 |
| 03-571 | F | 1909 | | 01 | 1925 | 52 | 1976 | 636 | B1 | 0.0 | Z9C | 195 | 0 | 2701 | 0 |
| 03-572 | F | 1906 | | 01 | 1924 | 56 | 1974 | 75 | B1 | 0.0 | Z9C | 23 | 0 | 320 | 0 |
| 03-573 | F | 1900 | | 01 | 1925 | 52 | 1974 | 14 | B1 | 0.0 | Z9C | 4 | 0 | 57 | 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 | 16 | 0 |
| 03-577 | F | 1901 | 1961 | 01 | 1921 | 104 | 1959 | 81 | C2 | 0.0 | Z9 | 21 | 0 | 247 | 0 |
| 03-578 | F | 1909 | | 01 | 1924 | 30 | 1976 | 8 | B2 | 0.0 | Z9 | 2 | 0 | 35 | 0 |
| 03-579 | F | 1905 | | 01 | 1922 | 13 | 1959 | 30 | C2 | 0.0 | Z9 | 8 | 0 | 113 | 0 |
| 03-580 | F | 1904 | | 01 | 1923 | 4 | 1959 | 2 | C6 | 0.0 | Z9 | 1 | 0 | 7 | 0 |
| 03-581 | F | 1904 | | 01 | 1922 | 10 | 1959 | 13 | C3 | 0.0 | Z9 | 3 | 0 | 49 | 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 | 316 | 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 | 45 | 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 | 422 | 0 |
| 03-591 | F | 1907 | | 17 | 1926 | 2340 | 1976 | 5 | B2 | 0.0 | Z9C | 1 | 0 | 10 | 0 |
| 03-592 | F | 1905 | | 01 | 1922 | 78 | 1966 | 123 | C2 | 0.0 | Z9 | 35 | 0 | 499 | 0 |
| 03-593 | F | 1905 | | 01 | 1922 | 4 | 1974 | 11 | C3 | 0.0 | Z9C | 3 | 0 | 49 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 03-594 | F | 1905 | 1968 | 01 | 1922 | 52 | 1959 | 41 | C2 | 0.0 | Z9 | 11 | 0 | 137 | 0 |
| 03-595 | F | 1902 | | 01 | 1927 | 52 | 1975 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 4 | 0 |
| 03-596 | F | 1904 | | 01 | 1922 | 8 | 1975 | 12 | B2 | 0.0 | Z9C | 4 | 0 | 53 | 0 |
| 03-597 | F | 1903 | | 16 | 1925 | 1300 | 1972 | 74 | B1 | 0.0 | Z9C | 18 | 0 | 212 | 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 | | 01 | 1925 | 104 | 1960 | 3 | C6 | 0.0 | Z9 | 1 | 0 | 10 | 0 |
| 03-603 | F | 1888 | | 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 | 9 | 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 | 1976 | 108 | B1 | 0.0 | Z9C | 34 | 0 | 492 | 0 |
| 03-608 | F | 1901 | 1976 | 01 | 1919 | 104 | 1960 | 19 | C2 | 0.0 | Z9 | 5 | 0 | 76 | 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 | 1915 | 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 | 403 | 0 |
| 03-615 | F | 1905 | | 01 | 1923 | 107 | 1975 | 14 | B1 | 0.0 | Z9 | 4 | 0 | 62 | 0 |
| 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 | 11 | 0 |
| 03-621 | F | 1916 | | 01 | 1944 | 208 | 1971 | 4 | B3 | 0.0 | Z9C | 1 | 0 | 8 | 0 |
| 03-622 | F | 1910 | | 01 | 1926 | 104 | 1960 | 0 | G6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |
| 03-623 | F | 1902 | | 01 | 1924 | +0 | 1963 | 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 | 706 | 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 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 03-630 | F | 1908 | | 01 | 1924 | 17 | 1974 | 19 | B1 | 0.0 | Z9C | 6 | 0 | 79 | 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 | 73 | 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 | 166 | 0 |
| 03-636 | F | 1904 | | 01 | 1924 | 192 | 1976 | 5 | B2 | 0.0 | Z9C | 2 | 0 | 23 | 0 |
| 03-637 | F | 1906 | | 01 | 1924 | 6 | 1976 | 40 | B1 | 0.0 | Z9C | 12 | 0 | 175 | 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 | 233 | 0 |
| 03-640 | F | 1902 | | 01 | 1924 | 60 | 1960 | 5 | C3 | 0.0 | Z9 | 1 | 0 | 18 | 0 |
| 03-641 | F | 1904 | | 01 | 1922 | 26 | 1976 | 8 | B2 | 0.0 | Z9C | 3 | 0 | 37 | 0 |
| 03-642 | F | 1905 | | 01 | 1922 | 52 | 1976 | 31 | B2 | 0.0 | Z9C | 10 | 0 | 143 | 0 |
| 03-643 | F | 1909 | | 01 | 1926 | 156 | 1975 | 10 | B2 | 0.0 | Z9C | 3 | 0 | 38 | 0 |
| 03-645 | F | 1906 | | 01 | 1924 | 312 | 1959 | 56 | C2 | 0.0 | Z9 | 14 | 0 | 195 | 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 | 123 | 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 |
| 03-671 | 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 | 120 | 0 |
| 03-674 | F | 1908 | | 01 | 1925 | 43 | 1976 | 2 | B3 | 0.0 | Z9C | 1 | 0 | 9 | 0 |
| 03-676 | F | 1897 | | 01 | 1924 | +0 | 1963 | 1700 | C2 | 0.0 | Z9 | 455 | 0 | 6433 | 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 | 2 | 0 |
| 03-679 | F | 1910 | | 01 | 1930 | 10 | 1972 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 5 | 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 | 1973 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 5 | 0 |
| 03-683 | F | 1906 | | 01 | 1923 | 0 | 1961 | 0 | C6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |
| 03-684 | F | 1907 | | 01 | 1927 | 17 | 1972 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 4 | 0 |
| 03-685 | F | 1902 | | 01 | 1921 | 65 | 1976 | 70 | B1 | 0.0 | Z9C | 22 | 0 | 323 | 0 |
| 03-686 | F | 1904 | | 01 | 1923 | 1040 | 1975 | 20 | B2 | 0.0 | Z9C | 6 | 0 | 84 | 0 |
| 03-687 | F | 1900 | 1974 | 01 | 1925 | 43 | 1961 | 51 | C2 | 0.0 | Z9 | 13 | 0 | 176 | 0 |
| 03-688 | F | 1918 | | 01 | 1936 | 260 | 1972 | 3 | B6 | 0.0 | Z9C | 1 | 0 | 7 | 0 |
| 03-689 | F | 1903 | | 01 | 1923 | 208 | 1961 | 130 | C2 | 0.0 | Z9 | 34 | 0 | 472 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 03-690 | F | 1909 | 1967 | 01 | 1924 | 290 | 1958 | 320 | C2 | 0.0 | Z9 | 78 | 0 | 965 | 0 |
| 03-692 | M | 1887 | | 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 | 18 | 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 | 715 | 0 |
| 03-703 | F | 1921 | | 01 | 1946 | 416 | 1974 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 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 | 7 | 0 |
| 03-716 | F | 1920 | 1976 | 01 | 1941 | 104 | 1971 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 03-720 | F | 1910 | | 01 | 1926 | 52 | 1976 | 6 | B2 | 0.0 | Z9C | 2 | 0 | 23 | 0 |
| 03-722 | F | 1905 | | 01 | 1924 | 26 | 1972 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 6 | 0 |
| 03-726 | F | 1905 | 1972 | 01 | 1922 | 186 | 1968 | 574 | C2 | 0.0 | Z9 | 164 | 0 | 2206 | 0 |
| 03-727 | F | 1906 | | 01 | 1923 | 988 | 1972 | 165 | B1 | 0.0 | Z9B | 49 | 0 | 687 | 0 |
| 03-729 | F | 1926 | | 01 | 1943 | 208 | 1973 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 3 | 0 |
| 03-730 | M | 1894 | 1963 | 06 | 1923 | +0 | 1961 | 7 | C3 | 0.0 | Z9 | 2 | 0 | 16 | 0 |
| 03-732 | F | 1924 | | 01 | 1942 | 78 | 1973 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 4 | 0 |
| 03-736 | F | 1895 | | 16 | 1919 | 22 | 1975 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 03-741 | F | 1908 | | 01 | 1925 | 260 | 1975 | 4 | B3 | 0.0 | Z9C | 1 | 0 | 15 | 0 |
| 03-752 | F | 1904 | | 01 | 1922 | 15 | 1972 | 7 | B3 | 0.0 | Z9C | 2 | 0 | 30 | 0 |
| 03-753 | F | 1906 | | 01 | 1922 | +0 | 1974 | 12 | B2 | 0.0 | Z9C | 4 | 0 | 54 | 0 |
| 03-757 | F | 1902 | | 01 | 1923 | 91 | 1974 | 14 | B2 | 0.0 | Z9C | 4 | 0 | 59 | 0 |
| 03-761 | F | 1901 | | 01 | 1927 | 1144 | 1974 | 19 | B2 | 0.0 | Z9C | 5 | 0 | 56 | 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 | 8 | 0 |
| 03-774 | F | 1909 | | 01 | 1924 | 3 | 1972 | 1 | C6 | 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 | 232 | 0 |
| 03-782 | F | 1908 | | 01 | 1923 | 5 | 1976 | 2 | B3 | 0.0 | Z9C | 1 | 0 | 11 | 0 |
| 03-784 | F | 1905 | | 01 | 1923 | +0 | 1954 | 750 | C4 | 0.0 | Z9 | 178 | 0 | 2550 | 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 | +0 | 1972 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 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 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 03-810 | F | 1919 | | 01 | 1934 | 312 | 1972 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 5 | 0 |
| 03-817 | F | 1907 | | 01 | 1926 | 13 | 1973 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 03-818 | F | 1902 | | 01 | 1927 | 62 | 1975 | 4 | B3 | 0.0 | Z9C | 1 | 0 | 16 | 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 | 1972 | 0 | B6 | 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 | | 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 | 12 | 0 |
| 03-845 | F | 1908 | | 01 | 1925 | 104 | 1974 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 03-850 | F | 1923 | | 01 | 1942 | 78 | 1976 | 13 | B1 | 0.0 | Z9C | 3 | 0 | 34 | 0 |
| 05-001 | F | 1900 | | 01 | 1919 | 52 | 1975 | 45 | B1 | 0.00056 | Z7B | 14 | 7 | 216 | 103 |
| 05-002 | F | 1903 | 1973 | 01 | 1917 | 104 | 1971 | 1 | B6 | 0.0 | Z9B | 0 | 0 | 5 | 0 |
| 05-003 | F | 1900 | 1959 | 01 | 1917 | 8 | 1958 | 0 | G6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |
| 05-004 | F | 1904 | | 01 | 1920 | 104 | 1959 | 12 | G6 | 0.01600 | Z7 | 3 | 5 | 46 | 77 |
| 05-005 | F | 1901 | | 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 | 99 | 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 | 51 | 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 | 1975 | 140 | B1 | 0.00106 | B6 | 46 | 49 | 693 | 735 |
| 05-015 | F | 1891 | | 01 | 1916 | 57 | 1970 | 1 | B6 | 0.0 | Z9B | 0 | 0 | 5 | 0 |
| 05-016 | M | 1891 | 1965 | 06 | 1916 | 100 | 1958 | 15 | G4 | 0.0 | Z9 | 4 | 0 | 40 | 0 |
| 05-017 | F | 1894 | | 01 | 1919 | +0 | 1968 | 5 | G6 | 0.00520 | Z7 | 2 | 3 | 23 | 46 |
| 05-018 | M | 1886 | | 06 | 1918 | 156 | 1971 | 4 | B3 | 0.00180 | Z7B | 1 | 1 | 13 | 12 |
| 05-019 | F | 1885 | 1968 | 01 | 1921 | 2 | 1960 | 0 | G6 | 0.01400 | Z7 | 0 | 0 | 0 | 0 |
| 05-020 | F | 1898 | | 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 | 412 | 53 |
| 05-037 | F | 1898 | | 01 | 1916 | 260 | 1971 | 2 | B6 | 0.0 | Z9B | 1 | 0 | 9 | 0 |
| 05-038 | F | 1901 | | 07 | 1916 | 156 | 1972 | 99 | G4 | 0.0 | Z9 | 32 | 0 | 482 | 0 |
| 05-039 | F | 1899 | | 01 | 1917 | 156 | 1976 | 25 | B2 | 0.00070 | Z7B | 8 | 6 | 124 | 93 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 05-040 | F | 1899 | | 01 | 1917 | 54 | 1971 | 10 | B2 | 0.0 | Z9B | 3 | 0 | 48 | 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 | 24 | 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 | 17 | 0 |
| 05-089 | F | 1900 | | 01 | 1916 | 78 | 1971 | 13 | B2 | 0.0 | Z9B | 4 | 0 | 64 | 0 |
| 05-092 | F | 1901 | | 01 | 1916 | 104 | 1959 | 6 | G6 | 0.0 | Z9 | 2 | 0 | 26 | 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 | 13 | 0 |
| 05-096 | F | 1901 | 1971 | 01 | 1918 | 26 | 1962 | 234 | C2 | 0.00050 | Z7C | 66 | 7 | 949 | 102 |
| 05-097 | M | 1892 | 1976 | 06 | 1918 | 26 | 1961 | 4 | CL | 0.00050 | Z7C | 1 | 0 | 12 | 1 |
| 05-100 | F | 1907 | | 01 | 1919 | 156 | 1968 | 4 | G6 | 0.00520 | Z7 | 1 | 2 | 17 | 30 |
| 05-101 | F | 1902 | | 01 | 1924 | 6 | 1964 | 4 | CL | 0.00850 | Z7C | 1 | 1 | 15 | 18 |
| 05-102 | F | 1900 | | 01 | 1915 | 364 | 1960 | 6 | C6 | 0.00350 | Z7C | 2 | 1 | 25 | 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 | | 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 | 1972 | 5 | B3 | 0.0 | Z9B | 2 | 0 | 24 | 0 |
| 05-119 | F | 1905 | | 01 | 1924 | 212 | 1974 | 16 | B2 | 0.00252 | Z7 | 5 | 5 | 67 | 70 |
| 05-120 | F | 1890 | | 07 | 1919 | 6 | 1959 | 5 | G6 | 0.00770 | Z7 | 1 | 1 | 20 | 20 |
| 05-121 | F | 1906 | | 01 | 1921 | 26 | 1970 | 9 | B2 | 0.00390 | Z7B | 3 | 4 | 40 | 60 |
| 05-122 | M | 1879 | 1962 | 07 | 1922 | 208 | 1959 | 11 | G6 | 0.01600 | Z7 | 3 | 3 | 23 | 33 |
| 05-123 | F | 1897 | 1972 | 01 | 1918 | 1 | 1960 | 4 | G6 | 0.00060 | Z7 | 1 | 0 | 16 | 2 |
| 05-125 | F | 1902 | | 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 | 51 | 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 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 05-133 | 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 | 38 | 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 | 1916 | +0 | 1965 | 490 | F4 | 0.0 | Z9F | 140 | 0 | 1770 | 0 |
| 05-142 | F | 1904 | | 01 | 1919 | 39 | 1960 | 11 | G6 | 0.00680 | Z7 | 3 | 3 | 45 | 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 | 26 | 27 |
| 05-154 | F | 1900 | | 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 | | 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 | 56 | 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 | 1969 | 11 | G6 | 0.00330 | Z7 | 3 | 4 | 49 | 61 |
| 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 | 2 | 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 | 0.00650 | Z7C | 1 | 2 | 11 | 17 |
| 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 | 15 | 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 | 1960 | 0 | G6 | 0.00320 | Z7 | 0 | 0 | 0 | 0 |
| 05-205 | F | 1907 | | 01 | 1924 | 208 | 1961 | 4 | CL | 0.0 | Z9C | 1 | 0 | 14 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 05-206 | 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 | 19 | 0 |
| 05-210 | F | 1899 | 1971 | 01 | 1916 | 158 | 1964 | 20 | G6 | 0.0 | Z9 | 6 | 0 | 84 | 0 |
| 05-212 | F | 1903 | | 07 | 1918 | 8 | 1965 | 4 | CL | 0.00030 | Z7C | 1 | 0 | 18 | 2 |
| 05-215 | F | 1886 | 1968 | 01 | 1920 | 52 | 1969 | 1410 | A1 | 0.00198 | A3 | 418 | 301 | 5571 | 4528 |
| 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 | 59 | 0 |
| 05-252 | F | 1890 | 1976 | 01 | 1917 | 52 | 1964 | 4 | CL | 0.0 | Z9C | 1 | 0 | 18 | 0 |
| 05-255 | M | 1886 | 1966 | 07 | 1920 | 104 | 1964 | 5 | C6 | 0.00850 | Z7C | 1 | 2 | 13 | 24 |
| 05-257 | F | 1895 | 1975 | 01 | 1932 | 1248 | 1972 | 3 | G6 | 0.0 | Z9 | 1 | 0 | 7 | 0 |
| 05-258 | F | 1901 | | 01 | 1917 | 1 | 1970 | 0 | G6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |
| 05-259 | F | 1900 | | 07 | 1917 | 52 | 1960 | 6 | G6 | 0.0 | Z9 | 2 | 0 | 26 | 0 |
| 05-260 | F | 1898 | | 07 | 1917 | 32 | 1960 | 0 | G6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |
| 05-261 | F | 1892 | | 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 | 12 | 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 | 17 | 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 | 25 | 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 | 1965 | 44 | G4 | 0.0 | Z9 | 13 | 0 | 174 | 0 |
| 05-279 | F | 1896 | | 01 | 1917 | 1820 | 1969 | 0 | G6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |
| 05-281 | F | 1898 | 1964 | 01 | 1916 | 148 | 1962 | 720 | B1 | 0.00250 | F1 | 206 | 116 | 2717 | 1743 |
| 05-282 | F | 1898 | | 01 | 1917 | 34 | 1964 | 8 | C6 | 0.0 | Z9C | 2 | 0 | 36 | 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 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 05-288 | F | 1897 | | 01 | 1918 | 10 | 1960 | 4 | CL | 0.00060 | Z7C | 1 | 0 | 17 | 2 |
| 05-290 | F | 1898 | 1967 | 01 | 1918 | 52 | 1960 | 8 | C3 | 0.00060 | Z7C | 2 | 0 | 30 | 3 |
| 05-291 | F | 1902 | 1974 | 01 | 1920 | 8 | 1968 | 4 | G6 | 0.00540 | Z7 | 1 | 2 | 17 | 33 |
| 05-292 | M | 1904 | 1974 | 07 | 1918 | +0 | 1965 | 4 | CL | 0.00033 | Z7C | 1 | 0 | 13 | 1 |
| 05-304 | F | 1897 | | 01 | 1921 | 25 | 1962 | 4 | CL | 0.01100 | Z7C | 1 | 2 | 16 | 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 |
| 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 | 72 | 80 |
| 05-322 | M | 1900 | 1975 | 07 | 1917 | 312 | 1973 | 4 | B3 | 0.0 | Z7B | 1 | 0 | 13 | 0 |
| 05-323 | F | 1899 | 1951 | 01 | 1915 | 25 | 1961 | 2 | A5 | 0.0 | Z9 | 1 | 0 | 7 | 0 |
| 05-351 | F | 1891 | | 01 | 1917 | 30 | 1968 | 23 | G6 | 0.0 | Z9 | 7 | 0 | 108 | 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 | 1973 | 1 | B6 | 0.0 | Z9B | 0 | 0 | 4 | 0 |
| 05-357 | F | 1890 | | 07 | 1917 | 104 | 1972 | 3 | G6 | 0.0 | Z9 | 1 | 0 | 14 | 0 |
| 05-360 | M | 1892 | 1968 | 01 | 1914 | +0 | 1963 | 4 | CL | 0.0 | Z9C | 1 | 0 | 12 | 0 |
| 05-363 | F | 1899 | | 07 | 1917 | 9 | 1964 | 4 | CL | 0.0 | Z9C | 1 | 0 | 18 | 0 |
| 05-368 | F | 1901 | | 07 | 1917 | 104 | 1972 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 5 | 0 |
| 05-369 | F | 1901 | | 07 | 1919 | 26 | 1973 | 1 | B6 | 0.00140 | Z7B | 0 | 0 | 5 | 5 |
| 05-370 | F | 1895 | | 01 | 1920 | 25 | 1965 | 4 | CL | 0.00760 | Z7C | 1 | 2 | 17 | 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 | 1964 | 4 | CL | 0.00850 | Z7C | 1 | 1 | 16 | 20 |
| 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 | 350 | 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 | 1970 | 10 | G6 | 0.0 | Z9 | 3 | 0 | 30 | 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 | 17 | 16 |
| 05-407 | F | 1898 | | 01 | 1916 | 9 | 1973 | 1 | B6 | 0.0 | Z9B | 0 | 0 | 5 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 05-409 | F | 1900 | | 07 | 1918 | 61 | 1974 | 0 | B6 | 0.00011 | Z7B | 0 | 0 | 0 | 0 |
| 05-410 | F | 1899 | | 01 | 1916 | 26 | 1971 | 2 | B6 | 0.0 | Z9B | 1 | 0 | 10 | 0 |
| 05-413 | F | 1900 | 1971 | 01 | 1916 | 39 | 1969 | 18 | B2 | 0.0 | Z9B | 6 | 0 | 82 | 0 |
| 05-420 | F | 1889 | 1935 | 01 | 1917 | 104 | 1970 | 50 | A1 | 0.0 | Z9A | 9 | 0 | 60 | 0 |
| 05-437 | F | 1888 | | 07 | 1923 | 26 | 1971 | 3 | B3 | 0.00350 | Z7B | 1 | 1 | 13 | 16 |
| 05-438 | F | 1907 | | 01 | 1926 | 13 | 1961 | 4 | CL | 0.0 | Z9C | 1 | 0 | 14 | 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 | 35 | 0 |
| 05-443 | F | 1922 | | 07 | 1941 | 52 | 1972 | 3 | B6 | 0.0 | Z9B | 1 | 0 | 8 | 0 |
| 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 | 18 | 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 | 21 | 0 |
| 05-460 | F | 1898 | | 07 | 1916 | 182 | 1961 | 4 | CL | 0.0 | Z9C | 1 | 0 | 17 | 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 | | 01 | 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 | 71 | 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 |
| 05-580 | 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 |
| 05-736 | 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 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 05-751 | 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 | 18 | 0 |
| 05-802 | F | 1893 | | 01 | 1918 | +0 | 1972 | 1 | B6 | 0.00014 | Z7B | 0 | 0 | 2 | 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 | 162 | 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 |
| 05-892 | F | 1904 | | 01 | 1917 | 4 | 1968 | 70 | G6 | 0.0 | Z9 | 22 | 0 | 331 | 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 | 10 | 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 | 5 | 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 | 373 | 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 | 325 | 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 |
| 05-962 | F | 1894 | | 01 | 1918 | 84 | 1964 | 47 | C2 | 0.00200 | Z7C | 14 | 7 | 204 | 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 | 926 | 0 |
| 05-985 | F | 1921 | 1976 | 01 | 1939 | 130 | 1965 | 5 | C6 | 0.0 | Z9C | 1 | 0 | 12 | 0 |
| 05-993 | M | 1902 | 1972 | 07 | 1917 | 6 | 1971 | 7 | B3 | 0.0 | Z9B | 2 | 0 | 23 | 0 |
| 05-994 | F | 1886 | | 01 | 1922 | 26 | 1967 | 9 | G4 | 0.00570 | Z7 | 3 | 3 | 37 | 51 |
| 05-998 | F | 1902 | | 01 | 1918 | 3 | 1974 | 0 | B6 | 0.00011 | Z7B | 0 | 0 | 0 | 0 |
| 09-001 | F | 1901 | | 01 | 1917 | 39 | 1971 | 4 | B3 | 0.0 | Z9B | 1 | 0 | 19 | 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 | 415 | 1960 | 550 | C2 | 0.0 | Z9C | 156 | 0 | 2013 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 09-006 | 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 | 1900 | | 01 | 1917 | 8 | 1960 | 20 | C6 | 0.0 | Z9C | 6 | 0 | 86 | 0 |
| 09-009 | F | 1893 | 1969 | 01 | 1915 | 78 | 1960 | 2 | B6 | 0.0 | Z9B | 1 | 0 | 8 | 0 |
| 09-010 | F | 1897 | 1964 | 01 | 1914 | +0 | 1960 | 10 | C6 | 0.0 | Z9C | 3 | 0 | 40 | 0 |
| 09-013 | F | 1900 | | 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 |
| 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 | 1975 | 19 | B2 | 0.0 | Z9B | 6 | 0 | 95 | 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 | 1250 | 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 | | 01 | 1917 | 26 | 1971 | 11 | B6 | 0.0 | Z9B | 3 | 0 | 53 | 0 |
| 09-044 | F | 1906 | 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 | 70 | 0 |
| 09-051 | F | 1900 | | 01 | 1917 | 104 | 1960 | 50 | C6 | 0.0 | Z9C | 14 | 0 | 211 | 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 | 17 | 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 | 19 | 0 |
| 09-064 | F | 1891 | | 01 | 1915 | 9 | 1973 | 1 | B6 | 0.0 | Z9B | 0 | 0 | 5 | 0 |
| 09-065 | F | 1887 | | 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 | | 01 | 1917 | 104 | 1975 | 2 | B6 | 0.0 | Z9B | 1 | 0 | 10 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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) RA223 TO RA226 RATIO | (12) RA228 METHOD + ERR | (13) INPUT RA226 UCI | (14) INPUT RA228 UCI | (15) CUM RADS RA226 | (16) CUM RADS RA228 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |
| 09-080 | M | 1886 | | 06 | 1919 | 312 | 1962 | 5 | G6 | 0.0 | Z9 | 1 | 0 | 14 | 0 |
| 09-082 | M | 1892 | | 06 | 1916 | 312 | 1974 | 4 | B3 | 0.0 | Z9B | 1 | 0 | 14 | 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 | | 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 | 52 | 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 | | 06 | 1919 | 17 | 1963 | 9 | G6 | 0.0 | Z9 | 3 | 0 | 27 | 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 | | 06 | 1918 | 364 | 1963 | 9 | G6 | 0.0 | Z9 | 2 | 0 | 26 | 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 | 728 | 1966 | 1390 | A1 | 0.00093 | A6 | 156 | 34 | 507 | 252 |
| 09-106 | M | 1901 | | 06 | 1919 | 156 | 1974 | 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 | 13 | 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 | 24 | 0 |
| 09-111 | M | 1874 | 1944 | 06 | 1913 | 520 | 1967 | 0 | A6 | 0.0 | Z9A | 0 | 0 | 0 | 0 |
| 09-112 | M | 1898 | | 06 | 1940 | 416 | 1966 | 84 | G4 | 0.0 | Z9 | 17 | 0 | 122 | 0 |
| 09-115 | M | 1893 | | 06 | 1920 | 52 | 1969 | 3 | G6 | 0.0 | Z9 | 1 | 0 | 9 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 09-117 | F | 1899 | | 01 | 1917 | 24 | 1971 | 4 | B3 | 0.0 | Z9B | 1 | 0 | 19 | 0 |
| 09-118 | F | 1901 | | 07 | 1921 | +0 | 1970 | 50 | G4 | 0.0 | Z9 | 15 | 0 | 221 | 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 | 1974 | 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 |
| 10-018 | F | 1920 | | 01 | 1952 | 416 | 1975 | 1 | B6 | 0.0 | Z9B | 0 | 0 | 1 | 0 |
| 10-024 | M | 1914 | | 06 | 1936 | 1612 | 1971 | 50 | G4 | 0.0 | Z9 | 8 | 0 | 51 | 0 |
| 10-025 | M | 1937 | | 07 | 1963 | 416 | 1971 | 7 | B3 | 0.0 | Z9C | 0 | 0 | 1 | 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 | | 06 | 1918 | 156 | 1976 | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 10-031 | F | 1928 | | 01 | 1946 | 52 | 1972 | 8 | B2 | 0.0 | Z9C | 2 | 0 | 17 | 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 | 20 | 0 |
| 10-035 | F | 1922 | | 01 | 1942 | 689 | 1974 | 10 | B2 | 0.0 | Z9C | 2 | 0 | 21 | 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 | 9 | 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 | 38 | 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 | 25 | 0 |
| 10-048 | F | 1894 | | 06 | 1917 | 156 | 1972 | 3 | B6 | 0.0 | Z9C | 1 | 0 | 14 | 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 | 26 | 0 |
| 10-051 | M | 1914 | | 06 | 1931 | 468 | 1972 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-053 | F | 1926 | | 17 | 1946 | 260 | 1972 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 3 | 0 |
| 10-054 | F | 1926 | | 71 | 1943 | 364 | 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 | 15 | 0 |
| 10-059 | F | 1915 | | 01 | 1944 | 104 | 1972 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-060 | F | 1919 | | 01 | 1943 | 104 | 1972 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-061 | F | 1923 | | 07 | 1939 | 260 | 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 | 6 | 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 | | 01 | 1942 | 104 | 1972 | 12 | B2 | 0.0 | Z9C | 3 | 0 | 28 | 0 |
| 10-067 | F | 1923 | | 01 | 1942 | 468 | 1972 | 8 | B2 | 0.0 | Z9C | 2 | 0 | 17 | 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 | 8 | B3 | 0.0 | Z9C | 1 | 0 | 5 | 0 |
| 10-070 | F | 1921 | | 01 | 1945 | 1352 | 1974 | 14 | B2 | 0.0 | Z9C | 2 | 0 | 14 | 0 |
| 10-071 | F | 1924 | | 01 | 1943 | 1508 | 1972 | 13 | B2 | 0.0 | Z9C | 1 | 0 | 10 | 0 |
| 10-072 | F | 1924 | | 01 | 1947 | 1300 | 1972 | 12 | B2 | 0.0 | Z9C | 1 | 0 | 8 | 0 |
| 10-073 | M | 1919 | | 07 | 1953 | 208 | 1972 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-074 | M | 1921 | | 06 | 1950 | 1248 | 1976 | 34 | B2 | 0.0 | Z9C | 5 | 0 | 20 | 0 |
| 10-075 | F | 1929 | | 01 | 1949 | 260 | 1972 | 5 | B3 | 0.0 | Z9C | 1 | 0 | 9 | 0 |
| 10-076 | F | 1923 | | 01 | 1951 | 52 | 1972 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-077 | F | 1920 | | 01 | 1951 | 17 | 1972 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 10-078 | F | 1923 | | 01 | 1941 | 676 | 1974 | 13 | B1 | 0.0 | Z9C | 3 | 0 | 28 | 0 |
| 10-079 | F | 1920 | | 01 | 1940 | 624 | 1974 | 13 | B3 | 0.0 | Z9C | 3 | 0 | 29 | 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 | 1972 | 5 | B3 | 0.0 | Z9C | 1 | 0 | 11 | 0 |
| 10-082 | F | 1915 | | 01 | 1951 | 758 | 1972 | 5 | B3 | 0.0 | Z9C | 1 | 0 | 5 | 0 |
| 10-083 | F | 1924 | | 01 | 1943 | 104 | 1972 | 5 | B3 | 0.0 | Z9C | 1 | 0 | 12 | 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 | 1972 | 3 | B6 | 0.0 | Z9C | 1 | 0 | 6 | 0 |
| 10-087 | F | 1920 | | 01 | 1942 | 1560 | 1972 | 19 | B2 | 0.0 | Z9C | 2 | 0 | 15 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (1) CASE | (2) SEX | (3) BCRN | (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-088 | F | 1923 | | 17 | 1946 | 260 | 1972 | 3 | B6 | 0.0 | Z9C | 1 | 0 | 5 | 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 | 3 | 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 | 10 | 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 |
| 10-098 | F | 1917 | | 01 | 1935 | 208 | 1972 | 4 | B3 | 0.0 | Z9C | 1 | 0 | 12 | 0 |
| 10-099 | F | 1924 | | 01 | 1942 | 104 | 1974 | 19 | B2 | 0.0 | Z9C | 4 | 0 | 47 | 0 |
| 10-100 | F | 1924 | | 76 | 1942 | 78 | 1972 | 7 | B3 | 0.0 | Z9C | 2 | 0 | 18 | 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 | 1972 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 4 | 0 |
| 10-104 | F | 1929 | | 01 | 1948 | 208 | 1972 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 4 | 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 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 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 | 5 | 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 | 31 | 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 | 1 | 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 | 21 | 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 | 1945 | 17 | 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 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-128 | F | 1923 | | 01 | 1942 | 364 | 1972 | 6 | B3 | 0.0 | Z9C | 1 | 0 | 14 | 0 |
| 10-129 | F | 1923 | | 01 | 1942 | 269 | 1975 | 9 | B2 | 0.0 | Z9C | 2 | 0 | 21 | 0 |
| 10-130 | F | 1922 | | 01 | 1942 | 147 | 1975 | 14 | B2 | 0.0 | Z9C | 3 | 0 | 35 | 0 |
| 10-131 | F | 1917 | | 07 | 1941 | 260 | 1972 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 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 | 8 | 0 |
| 10-134 | F | 1913 | | 01 | 1932 | 1872 | 1972 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 10-135 | F | 1922 | | 01 | 1939 | 130 | 1972 | 6 | B3 | 0.0 | Z9C | 1 | 0 | 16 | 0 |
| 10-136 | F | 1920 | | 01 | 1941 | 26 | 1972 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-137 | F | 1918 | | 01 | 1935 | 117 | 1972 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 10-139 | F | 1922 | | 01 | 1942 | 130 | 1972 | 3 | B6 | 0.0 | Z9C | 1 | 0 | 7 | 0 |
| 10-140 | F | 1935 | | 07 | 1956 | 17 | 1972 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 10-141 | F | 1918 | | 01 | 1965 | 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 | 5 | 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 | 12 | 0 |
| 10-146 | F | 1921 | | 01 | 1940 | 364 | 1972 | 4 | B3 | 0.0 | Z9C | 1 | 0 | 8 | 0 |
| 10-147 | F | 1927 | | 01 | 1946 | 156 | 1972 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 4 | 0 |
| 10-148 | F | 1913 | | 01 | 1935 | 13 | 1972 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-149 | F | 1924 | | 01 | 1945 | 104 | 1972 | 4 | B3 | 0.0 | Z9C | 1 | 0 | 9 | 0 |
| 10-150 | F | 1889 | 1973 | 01 | 1919 | 13 | 1972 | 0 | G6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |
| 10-151 | M | 1887 | | 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 | 2 | 0 |
| 10-160 | F | 1921 | | 01 | 1941 | 208 | 1976* | 20 | B1 | 0.0 | Z9C | 5 | 0 | 52 | 0 |
| 10-162 | F | 1931 | | 01 | 1951 | 13 | 1974 | 3 | B2 | 0.0 | Z9C | 1 | 0 | 5 | 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 | 4 | 0 |
| 10-171 | F | 1924 | | 01 | 1942 | 156 | 1974 | 3 | B3 | 0.0 | Z9C | 1 | 0 | 7 | 0 |
| 10-172 | F | 1930 | | 07 | 1948 | 60 | 1974 | 3 | B3 | 0.0 | Z9C | 1 | 0 | 7 | 0 |
| 10-173 | F | 1915 | | 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 | 18 | 0 |
| 10-181 | F | 1912 | | 01 | 1931 | 287 | 1973 | 5 | B3 | 0.0 | Z9C | 1 | 0 | 15 | 0 |
| 10-190 | F | 1921 | | 01 | 1946 | 156 | 1972 | 3 | B6 | 0.0 | Z9C | 1 | 0 | 6 | 0 |
| 10-191 | F | 1940 | | 71 | 1971 | 17 | 1972 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-192 | 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 | | 01 | 1937 | 1560 | 1973 | 11 | C3 | 0.0 | Z9C | 2 | 0 | 17 | 0 |
| 10-198 | F | 1920 | | 01 | 1946 | 378 | 1973 | 15 | B2 | 0.0 | Z9C | 3 | 0 | 28 | 0 |
| 10-201 | F | 1918 | | 71 | 1946 | 1352 | 1972 | 9 | B2 | 0.0 | Z9C | 1 | 0 | 6 | 0 |
| 10-202 | F | 1925 | | 01 | 1947 | 49 | 1974 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 4 | 0 |
| 10-203 | F | 1926 | | 01 | 1946 | 0 | 1974 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 4 | 0 |
| 10-204 | F | 1950 | | 07 | 1971 | 43 | 1972 | 6 | B3 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 10-205 | F | 1923 | | 01 | 1942 | 39 | 1972 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 3 | 0 |
| 10-206 | F | 1924 | | 01 | 1943 | 230 | 1972 | 6 | B3 | 0.0 | Z9C | 1 | 0 | 14 | 0 |
| 10-207 | F | 1923 | | 61 | 1942 | 208 | 1972 | 12 | B2 | 0.0 | Z9C | 3 | 0 | 27 | 0 |
| 10-208 | F | 1922 | | 01 | 1941 | 2 | 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 | 14 | 0 |
| 10-210 | F | 1909 | | 01 | 1926 | 1040 | 1972 | 17 | B2 | 0.0 | Z9C | 4 | 0 | 50 | 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 | 1 | 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 | 1976 | 13 | B2 | 0.0 | Z9B | 3 | 0 | 36 | 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 | 2288 | 1972 | 6 | B3 | 0.0 | Z9C | 1 | 0 | 5 | 0 |
| 10-228 | F | 1912 | | 01 | 1940 | 1508 | 1975 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-229 | F | 1920 | | 01 | 1942 | 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 |
| 10-233 | F | 1919 | | 01 | 1941 | 52 | 1976* | 2 | B3 | 0.0 | Z9C | 1 | 0 | 5 | 0 |
| 10-234 | F | 1928 | 1972 | 07 | 1959 | 884 | 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 | 1972 | 4 | B3 | 0.0 | Z9C | 1 | 0 | 11 | 0 |
| 10-239 | M | 1908 | | 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 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 RATIC | (12) RA228 METHOD + ERR | (13) INPUT RA226 UCI | (14) INPUT RA228 UCI | (15) CUM RADS RA226 | (16) CUM RADS RA228 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-241 | F | 1904 | | 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 | 1942 | 1 | 1972 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 10-245 | M | 1914 | | 67 | 1941 | 104 | 1972 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-247 | M | 1915 | 1976 | 07 | 1948 | 364 | 1972 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 10-249 | M | 1943 | | 07 | 1963 | 130 | 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 | 415 | 1972 | 4 | B3 | 0.0 | Z9C | 1 | 0 | 11 | 0 |
| 10-254 | F | 1905 | | 07 | 1953 | 832 | 1976 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-256 | F | 1917 | | 01 | 1940 | 73 | 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 | 0 | 0 |
| 10-258 | F | 1923 | | 01 | 1943 | 26 | 1972 | 3 | B6 | 0.0 | Z9C | 1 | 0 | 7 | 0 |
| 10-261 | F | 1922 | | 01 | 1940 | 104 | 1972 | 3 | B6 | 0.0 | Z9C | 1 | 0 | 7 | 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 | 1925 | 2236 | 1973 | 2 | B6 | 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 | 1945 | 104 | 1972 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 10-272 | F | 1915 | | 01 | 1935 | 52 | 1972 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 5 | 0 |
| 10-273 | F | 1929 | | 01 | 1948 | 22 | 1973 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 4 | 0 |
| 10-274 | F | 1924 | | 01 | 1946 | 62 | 1973 | 3 | B3 | 0.0 | Z9C | 1 | 0 | 7 | 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 | 1 | 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 | 5 | 0 |
| 10-285 | M | 1917 | | 07 | 1935 | 8 | 1973 | 0 | G6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |
| 10-286 | F | 1937 | | 07 | 1968 | 104 | 1973 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-287 | F | 1923 | | 01 | 1948 | 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 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-292 | 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 | 4 | 0 |
| 10-295 | M | 1923 | | 07 | 1946 | 282 | 1973 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 10-296 | F | 1930 | | 01 | 1948 | 50 | 1973 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-297 | F | 1929 | 1973 | 07 | 1969 | 66 | 1973 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-299 | F | 1923 | | 01 | 1942 | 43 | 1973 | 6 | B3 | 0.0 | Z9C | 2 | 0 | 16 | 0 |
| 10-300 | F | 1911 | | 01 | 1940 | 1612 | 1973 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 10-301 | M | 1930 | | 07 | 1949 | 69 | 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 | 21 | 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 | 1936 | 53 | 1973 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 5 | 0 |
| 10-311 | F | 1919 | | 01 | 1943 | 16 | 1973 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-312 | F | 1923 | | 01 | 1943 | 16 | 1973 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 4 | 0 |
| 10-313 | F | 1924 | | 01 | 1942 | 110 | 1973 | 9 | B3 | 0.0 | Z9C | 2 | 0 | 22 | 0 |
| 10-314 | F | 1918 | | 01 | 1943 | 119 | 1973 | 4 | B3 | 0.0 | Z9C | 1 | 0 | 9 | 0 |
| 10-316 | M | 1946 | | 07 | 1965 | 167 | 1973 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 10-319 | F | 1912 | | 07 | 1934 | 832 | 1973 | 6 | B3 | 0.0 | Z9C | 1 | 0 | 15 | 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 | 10 | 0 |
| 10-324 | F | 1912 | | 01 | 1926 | 13 | 1973 | 0 | B6 | 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 |
| 10-329 | F | 1914 | | 07 | 1938 | 884 | 1973 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 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 |
| 10-333 | F | 1915 | | 01 | 1941 | 208 | 1973 | 1 | B6 | 0.0 | Z9B | 0 | 0 | 2 | 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 1976

| (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 | 0.0C260 | Z8 | 0 | 0 | 0 | 0 |
| 10-340 | F | 1920 | | 67 | 1942 | 104 | 1974 | 6 | B3 | 0.0 | Z9B | 1 | 0 | 15 | 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 | 1 | 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 | 2 | 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 | 1947 | 46 | 1973 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 10-357 | F | 1923 | | 01 | 1942 | 68 | 1973 | 3 | B3 | 0.0 | Z9C | 1 | 0 | 8 | 0 |
| 10-358 | F | 1920 | | 01 | 1946 | 16 | 1973 | 3 | B3 | 0.0 | Z9C | 1 | 0 | 6 | 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 | 9 | 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 |
| 10-375 | F | 1924 | | 01 | 1943 | 20 | 1973 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 3 | 0 |
| 10-377 | F | 1898 | | 07 | 1923 | 1976 | 1976 | 3 | B2 | 0.0 | Z9C | 1 | 0 | 8 | 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 | 1973 | 25 | B1 | 0.0 | Z9C | 6 | 0 | 65 | 0 |
| 10-381 | F | 1927 | | 01 | 1945 | 27 | 1973 | 6 | B3 | 0.0 | Z9C | 1 | 0 | 12 | 0 |
| 10-382 | F | 1923 | | 01 | 1942 | 119 | 1973 | 5 | B3 | 0.0 | Z9C | 1 | 0 | 13 | 0 |
| 10-384 | F | 1919 | | 71 | 1943 | 884 | 1973 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 10-385 | F | 1921 | | 07 | 1964 | 16 | 1973 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-386 | F | 1933 | | 01 | 1953 | 52 | 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 | 23 | 0 |
| 10-394 | F | 1907 | 1975 | 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 |
| 10-398 | F | 1918 | | 71 | 1951 | 624 | 1973 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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) RA226 TO RA226 RATIO | (12) RA228 METHOD + ERR | (13) INPUT RA226 UCI | (14) INPUT RA228 UCI | (15) CUM RADS RA226 | (16) CUM RADS RA228 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-409 | F | 1921 | | 01 | 1943 | 118 | 1973 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-410 | F | 1926 | | 01 | 1943 | 52 | 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 | 7 | 0 |
| 10-412 | F | 1908 | | 01 | 1925 | 13 | 1976 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 3 | 0 |
| 10-414 | F | 1926 | | 01 | 1948 | 104 | 1973 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 10-415 | F | 1943 | | 07 | 1973 | 8 | 1974 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-419 | M | 1913 | | 06 | 1936 | 1924 | 1973 | 6 | B3 | 0.0 | Z9C | 1 | 0 | 4 | 0 |
| 10-432 | F | 1920 | | 01 | 1940 | 104 | 1975 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 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 |
| 10-444 | 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 | 5 | 0 |
| 10-446 | F | 1920 | | 01 | 1939 | 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 | 13 | 0 |
| 10-449 | F | 1923 | | 01 | 1942 | 52 | 1976* | 4 | B2 | 0.0 | Z9C | 1 | 0 | 9 | 0 |
| 10-451 | F | 1921 | | 01 | 1945 | 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 | 1973 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-457 | F | 1921 | | 01 | 1941 | 65 | 1973 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 3 | 0 |
| 10-458 | M | 1927 | | 01 | 1954 | 1040 | 1973 | 24 | B2 | 0.0 | Z9C | 2 | 0 | 8 | 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 | 4 | 0 |
| 10-462 | M | 1927 | | 06 | 1951 | 1144 | 1973 | 8 | B3 | 0.0 | Z9C | 1 | 0 | 3 | 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 | 1943 | 176 | 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 |
| 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 | 1945 | 11 | 1973 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-477 | F | 1924 | | 01 | 1944 | 42 | 1975 | 2 | B3 | 0.0 | Z9C | 1 | 0 | 6 | 0 |
| 10-478 | F | 1922 | | 01 | 1940 | 10 | 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 | 1940 | 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 | 11 | 0 |
| 10-483 | M | 1934 | | 07 | 1950 | 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 | 19 | 0 |
| 10-492 | F | 1925 | | 01 | 1945 | 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 | 12 | 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 | 1973 | 2 | B6 | 0.0 | Z9B | 0 | 0 | 4 | 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 | 1 | 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 | 0 | 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 |
| 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 | 4 | 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 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-538 | M | 1896 | | 07 | 1941 | 1664 | 1973 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 10-540 | M | 1917 | | 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 | 1973 | 5 | B3 | 0.0 | Z9C | 1 | 0 | 17 | 0 |
| 10-549 | F | 1919 | | 01 | 1941 | 62 | 1973 | 4 | B3 | 0.0 | Z9C | 1 | 0 | 11 | 0 |
| 10-550 | F | 1914 | | 17 | 1965 | 230 | 1973 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-557 | F | 1921 | | 01 | 1942 | 43 | 1974 | 4 | B3 | 0.0 | Z9C | 1 | 0 | 10 | 0 |
| 10-558 | M | 1927 | | 07 | 1951 | +0 | 1973 | 5 | B3 | 0.0 | Z9C | 1 | 0 | 6 | 0 |
| 10-559 | F | 1919 | | 01 | 1941 | 69 | 1973 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 4 | 0 |
| 10-560 | F | 1923 | | 01 | 1942 | 96 | 1973 | 4 | B3 | 0.0 | Z9C | 1 | 0 | 9 | 0 |
| 10-561 | M | 1906 | | 06 | 1927 | 52 | 1973 | 6 | B6 | 0.0 | Z9B | 2 | 0 | 17 | 0 |
| 10-566 | M | 1914 | | 02 | 1930 | 13 | 1976 | 5 | B2 | 0.00334 | Z5B | 1 | 1 | 14 | 14 |
| 10-569 | F | 1925 | | 01 | 1946 | 1 | 1975 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-570 | M | 1907 | | 06 | 1934 | 780 | 1973 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 10-573 | F | 1922 | | 01 | 1944 | 14 | 1973 | 3 | B3 | 0.0 | Z9C | 1 | 0 | 6 | 0 |
| 10-574 | M | 1908 | | 71 | 1930 | 2236 | 1973 | 7 | B2 | 0.0 | Z9C | 1 | 0 | 6 | 0 |
| 10-575 | F | 1930 | | 01 | 1948 | 1040 | 1973 | 4 | B3 | 0.0 | Z9C | 1 | 0 | 4 | 0 |
| 10-579 | M | 1926 | | 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 | 5 | 0 |
| 10-582 | F | 1938 | | 01 | 1965 | 416 | 1973 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-583 | M | 1918 | | 06 | 1939 | 1352 | 1973 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-584 | F | 1925 | | 01 | 1942 | 3 | 1973 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 10-585 | M | 1908 | | 06 | 1930 | 52 | 1973 | 2 | B6 | 0.0 | Z9C | 1 | 0 | 5 | 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 | 780 | 1973 | 2 | B3 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-590 | M | 1912 | | 06 | 1948 | 728 | 1974 | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 10-592 | M | 1899 | | 06 | 1923 | 1300 | 1973 | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 10-594 | F | 1917 | | 01 | 1943 | 5 | 1973 | 5 | B3 | 0.0 | Z9C | 1 | 0 | 12 | 0 |
| 10-596 | F | 1909 | | 01 | 1927 | 6 | 1973 | 6 | B3 | 0.0 | Z9C | 2 | 0 | 22 | 0 |
| 10-597 | F | 1911 | | 01 | 1928 | 17 | 1976* | 2 | B3 | 0.0 | Z9C | 1 | 0 | 8 | 0 |
| 10-598 | F | 1914 | | 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 | 1936 | 4 | 1975 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-609 | 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 | 2 | 0 |
| 10-616 | F | 1929 | | 01 | 1948 | 15 | 1973 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 3 | 0 |
| 10-617 | F | 1922 | | 01 | 1942 | 182 | 1974 | 10 | B2 | 0.0 | Z9C | 2 | 0 | 24 | 0 |
| 10-618 | F | 1923 | | 01 | 1942 | 130 | 1975 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 10-621 | M | 1905 | | 06 | 1925 | 1716 | 1973 | 1 | B6 | 0.0 | Z9B | 0 | 0 | 1 | 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 |
| 10-644 | M | 1870 | 1927 | 05 | 1927 | 0 | 1975 | 5300 | A1 | 0.0 | Z9 | 4 | 0 | 4 | 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 | 4 | 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 | 16 | 0 |
| 10-651 | F | 1923 | | 01 | 1942 | 260 | 1974 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-653 | F | 1926 | | 01 | 1946 | 16 | 1973 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 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 | 23 | 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 | 44 | 0 |
| 10-662 | F | 1909 | | 01 | 1930 | 13 | 1973 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 10-664 | F | 1925 | | 01 | 1940 | 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 | 1 | 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 | | 06 | 1936 | 1040 | 1974 | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-673 | 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 | 6 | 0 |
| 10-714 | F | 1908 | | 01 | 1925 | 57 | 1974 | 0 | B6 | 0.00230 | Z4B | 0 | 0 | 0 | 0 |
| 10-725 | M | 1927 | | 07 | 1952 | 1 | 1973 | 5 | B2 | 0.0 | Z9C | 1 | 0 | 6 | 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 | 1974 | 4 | B6 | 0.0 | Z9C | 1 | 0 | 13 | 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 | 1 | 0 |
| 10-739 | F | 1931 | | 01 | 1951 | 7 | 1974 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 10-742 | F | 1929 | | 07 | 1946 | 1 | 1974 | 2 | B3 | 0.0 | Z9C | 0 | 0 | 4 | 0 |
| 10-744 | F | 1890 | | 05 | 1925 | 0 | 1975 | 120 | G4 | 0.0 | Z9 | 37 | 0 | 510 | 0 |
| 10-754 | F | 1881 | | 05 | 1925 | 0 | 1975 | 12 | G4 | 0.0 | Z9 | 4 | 0 | 51 | 0 |
| 10-786 | F | 1866 | 1928 | 05 | 1927 | 0 | 1976* | 1360 | A4 | 0.0 | Z9 | 54 | 0 | 71 | 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 | 1976* | 1073 | B1 | 0.0 | Z9B | 323 | 0 | 3141 | 0 |
| 10-840 | M | 1869 | 1926 | 05 | 1925 | 0 | 1976* | 390 | A1 | 0.0 | Z9 | 16 | 0 | 15 | 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 | | 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 | 1974 | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 10-855 | F | 1928 | | 01 | 1946 | 28 | 1976* | 7 | B2 | 0.0 | Z9C | 2 | 0 | 15 | 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 | 7 | 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 | 1300 | 1974 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-867 | F | 1915 | | 07 | 1929 | 209 | 1974 | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-869 | F | 1902 | | 01 | 1927 | 132 | 1974 | 0 | B6 | 0.00330 | Z8B | 0 | 0 | 0 | 0 |
| 10-870 | F | 1911 | | 07 | 1944 | 650 | 1974 | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 10-874 | F | 1924 | | 01 | 1942 | 728 | 1974 | 4 | B3 | 0.0 | Z9B | 1 | 0 | 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 | 1974 | 0 | B6 | 0.00330 | Z8B | 0 | 0 | 0 | 0 |
| 10-893 | F | 1926 | | 01 | 1943 | 78 | 1974 | 11 | B2 | 0.0 | Z9C | 3 | 0 | 27 | 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 | 4 | 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 | | 07 | 1958 | 52 | 1976* | 1 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 10-907 | F | 1910 | | 01 | 1946 | 5 | 1974 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 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 | 6 | 0 |
| 10-911 | F | 1928 | | 01 | 1947 | 2 | 1974 | 2 | B6 | 0.0 | Z9C | 0 | 0 | 4 | 0 |
| 10-915 | F | 1931 | | 01 | 1953 | 0 | 1974 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 10-916 | F | 1915 | | 01 | 1946 | 2 | 1974 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-918 | F | 1907 | | 01 | 1923 | 0 | 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 |
| 10-928 | M | 1918 | | 07 | 1948 | 0 | 1958* | 1 | G6 | 0.0 | Z9 | 0 | 0 | 1 | 0 |
| 10-931 | M | 1911 | | 01 | 1946 | 1040 | 1974 | 5 | B2 | 0.0 | Z9C | 1 | 0 | 5 | 0 |
| 10-932 | M | 1903 | | 76 | 1919 | 208 | 1974 | 14 | B2 | 0.0 | Z9B | 4 | 0 | 46 | 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 | 1974 | 9 | B2 | 0.0 | Z9C | 2 | 0 | 23 | 0 |
| 10-948 | F | 1923 | | 01 | 1943 | 3 | 1974 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-949 | 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 | 12 | 0 |
| 10-951 | F | 1916 | | 01 | 1943 | 8 | 1974 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 10-952 | F | 1911 | | 01 | 1927 | 10 | 1974 | 1 | B6 | 0.00329 | Z8B | 0 | 0 | 4 | 4 |
| 10-955 | F | 1922 | | 01 | 1942 | 104 | 1974 | 1 | B6 | 0.0 | Z9B | 0 | 0 | 2 | 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 | 8 | 0 |
| 10-963 | F | 1901 | | 01 | 1919 | 10 | 1975 | 647 | B1 | 0.00170 | B3B | 209 | 318 | 3132 | 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 |
| 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 | 15 | 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 | 2 | 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 | 1945 | 52 | 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 | 1974 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 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 | 1974 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 10-996 | F | 1900 | | 07 | 1943 | 806 | 1974 | 7 | G3 | 0.0 | Z9 | 1 | 0 | 12 | 0 |
| 10-997 | F | 1926 | | 07 | 1945 | 572 | 1974 | 8 | G3 | 0.0 | Z9 | 2 | 0 | 15 | 0 |
| 10-998 | F | 1909 | | 07 | 1942 | 988 | 1974 | 7 | G6 | 0.0 | Z9 | 1 | 0 | 12 | 0 |
| 11-002 | F | 1919 | | 01 | 1951 | 130 | 1976* | 0 | G6 | 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 | 1974 | 0 | G6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11-005 | M | 1926 | | 17 | 1948 | 520 | 1974 | 2 | G6 | 0.0 | Z9 | 0 | 0 | 2 | 0 |
| 11-009 | F | 1913 | | 07 | 1942 | 834 | 1974 | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 11-010 | F | 1922 | | 07 | 1942 | 572 | 1974 | 0 | G6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |
| 11-015 | F | 1907 | | 01 | 1925 | 2 | 1976* | 0 | G6 | 0.01000 | Z2 | 0 | 0 | 0 | 0 |
| 11-018 | F | 1908 | | 01 | 1925 | 5 | 1974 | 0 | B6 | 0.00330 | Z8B | 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 | | 71 | 1948 | 312 | 1974 | 0 | G6 | 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 | 7 | 0 |
| 11-032 | M | 1931 | | 06 | 1956 | 936 | 1974 | 3 | B3 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 11-033 | M | 1951 | | 06 | 1973 | 104 | 1975 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 11-034 | M | 1915 | | 06 | 1934 | 2080 | 1974 | 60 | B2 | 0.0 | Z9C | 8 | 0 | 44 | 0 |
| 11-036 | M | 1914 | | 07 | 1946 | 1456 | 1974 | 7 | B2 | 0.0 | Z9C | 1 | 0 | 3 | 0 |
| 11-038 | M | 1914 | | 06 | 1940 | 1456 | 1974 | 18 | B2 | 0.0 | Z9C | 3 | 0 | 18 | 0 |
| 11-040 | M | 1915 | | 67 | 1939 | 1560 | 1974 | 6 | B3 | 0.0 | Z9C | 1 | 0 | 6 | 0 |
| 11-042 | M | 1923 | | 07 | 1946 | 1456 | 1974 | 5 | B3 | 0.0 | Z9C | 1 | 0 | 2 | 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 |
| 11-056 | 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 |
| 11-119 | F | 1918 | | 01 | 1941 | 117 | 1976* | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 11-161 | F | 1921 | | 01 | 1940 | 130 | 1976* | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 11-207 | M | 1917 | | 01 | 1939 | 208 | 1974 | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 11-230 | F | 1904 | | 07 | 1942 | 104 | 1976* | 4 | B6 | 0.0 | Z9B | 1 | 0 | 10 | 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 | 208 | 1974 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 11-291 | F | 1919 | | 17 | 1951 | 164 | 1974 | 3 | B3 | 0.0 | Z9C | 1 | 0 | 4 | 0 |
| 11-294 | M | 1943 | | 07 | 1968 | 6 | 1974 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 11-296 | M | 1923 | | 07 | 1961 | 156 | 1976* | 45 | G3 | 0.0 | Z9 | 7 | 0 | 30 | 0 |
| 11-297 | M | 1914 | | 67 | 1934 | 1872 | 1976* | 9 | B2 | 0.0 | Z9C | 2 | 0 | 10 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11-302 | F | 1901 | | 01 | 1924 | 0 | 1976* | 0 | B6 | 0.01000 | Z2B | 0 | 0 | 0 | 0 |
| 11-389 | F | 1908 | | 01 | 1924 | 7 | 1976* | 3 | B3 | 0.01150 | Z2B | 1 | 6 | 13 | 89 |
| 11-453 | F | 1923 | | 01 | 1942 | 13 | 1976* | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 11-468 | M | 1918 | | 06 | 1947 | 676 | 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 | | 01 | 1918 | 54 | 1975 | 3 | G6 | 0.00160 | Z5 | 1 | 2 | 15 | 22 |
| 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 |
| 11-637 | M | 1902 | | 06 | 1934 | 52 | 1975 | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 11-655 | M | 1922 | | 06 | 1953 | 156 | 1976* | 1 | B3 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 11-660 | F | 1928 | | 01 | 1947 | 416 | 1976* | 5 | B2 | 0.0 | Z9C | 1 | 0 | 9 | 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 |
| 11-863 | F | 1916 | | 01 | 1942 | 52 | 1976* | 15 | G6 | 0.0 | Z9 | 4 | 0 | 39 | 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 | 1 | 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 | 8 | 0 |
| 11-960 | F | 1924 | | 01 | 1942 | 31 | 1975 | 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 |
| 11-982 | F | 1922 | | 01 | 1942 | 208 | 1976* | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 11-991 | F | 1924 | | 01 | 1942 | 6 | 1976* | 2 | B6 | 0.0 | Z9B | 1 | 0 | 5 | 0 |
| 12-002 | F | 1918 | | 01 | 1941 | 52 | 1976* | 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 | 166 | 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 |
| 12-040 | F | 1921 | | 01 | 1942 | 156 | 1976* | 3 | G6 | 0.0 | Z9 | 1 | 0 | 8 | 0 |
| 12-061 | F | 1920 | | 01 | 1942 | 182 | 1975 | 1 | B6 | 0.0 | Z9B | 0 | 0 | 2 | 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 |
| 12-098 | F | 1930 | | 01 | 1951 | 52 | 1974 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 12-099 | F | 1929 | | 07 | 1950 | 156 | 1976* | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 12-108 | F | 1915 | | 01 | 1943 | 26 | 1974 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12-110 | F | 1927 | | 01 | 1945 | 13 | 1976* | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 12-111 | F | 1929 | | 01 | 1947 | 19 | 1974 | 4 | B3 | 0.0 | Z9C | 1 | 0 | 8 | 0 |
| 12-113 | F | 1915 | | 01 | 1940 | 22 | 1975 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 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 | 1974 | 3 | B3 | 0.0 | Z9C | 1 | 0 | 8 | 0 |
| 12-119 | F | 1938 | | 17 | 1968 | 52 | 1975 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 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 |
| 12-129 | 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 | 10 | 0 |
| 12-133 | F | 1926 | | 01 | 1944 | 104 | 1976* | 1 | B3 | 0.0 | Z9C | 0 | 0 | 3 | 0 |
| 12-134 | F | 1927 | | 01 | 1944 | 4 | 1975 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 12-136 | F | 1928 | | 07 | 1965 | 30 | 1975 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 12-142 | F | 1922 | | 01 | 1942 | 8 | 1976* | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 12-143 | F | 1924 | | 01 | 1941 | 52 | 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 |
| 12-148 | 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 | 15 | 0 |
| 12-155 | F | 1929 | | 01 | 1955 | 52 | 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 | 10 | 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 | 7 | 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 | 1949 | 1 | 1974 | 2 | B3 | 0.0 | Z9C | 0 | 0 | 4 | 0 |
| 12-174 | F | 1924 | | 01 | 1947 | 21 | 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 |
| 12-185 | 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 | 17 | 0 |
| 12-188 | F | 1936 | | 07 | 1965 | 1 | 1976* | 1 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 12-190 | F | 1927 | | 01 | 1948 | 8 | 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 | 3 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12-195 | F | 1925 | | 01 | 1945 | 2 | 1976* | 1 | B3 | 0.0 | Z9C | 0 | 0 | 3 | 0 |
| 12-197 | F | 1906 | | 01 | 1922 | 26 | 1974 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 3 | 0 |
| 12-198 | M | 1909 | | 17 | 1929 | 520 | 1976* | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 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 |
| 12-304 | F | 1923 | | 01 | 1943 | 52 | 1975 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 12-308 | F | 1900 | | 01 | 1942 | 52 | 1975 | 2 | B3 | 0.0 | Z9C | 1 | 0 | 5 | 0 |
| 12-330 | M | 1928 | | 07 | 1944 | 63 | 1974 | 1 | B6 | 0.0 | Z9B | 0 | 0 | 2 | 0 |
| 12-331 | M | 1930 | | 07 | 1944 | 65 | 1974 | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 12-333 | M | 1932 | | 06 | 1955 | 728 | 1974 | 3 | B3 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 12-334 | F | 1908 | | 01 | 1924 | 17 | 1975 | 4 | B3 | 0.0 | Z9C | 1 | 0 | 18 | 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 | 13 | 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 | 1974 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 5 | 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 | 17 | 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 |
| 12-377 | F | 1920 | | 01 | 1961 | 676 | 1975 | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 12-397 | M | 1916 | | 06 | 1947 | 520 | 1975 | 28 | B2 | 0.0 | Z9B | 6 | 0 | 35 | 0 |
| 12-422 | F | 1907 | | 01 | 1937 | 39 | 1975 | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 12-425 | M | 1938 | | 07 | 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 | 1923 | 13 | 1976 | 184 | B1 | 0.0 | Z9C | 58 | 0 | 826 | 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 |
| 12-436 | F | 1896 | | 01 | 1918 | 26 | 1975 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 3 | 0 |
| 12-437 | F | 1926 | | 01 | 1943 | 104 | 1975 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 3 | 0 |
| 12-443 | M | 1919 | | 06 | 1945 | 13 | 1976* | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 12-447 | M | 1918 | | 06 | 1940 | 260 | 1976* | 6 | B2 | 0.0 | Z9C | 2 | 0 | 12 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12-456 | M | 1918 | | 06 | 1938 | 364 | 1976* | 249 | B1 | 0.0 | Z9C | 62 | 0 | 482 | 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 | 1975 | 2 | C6 | 0.0 | Z9C | 1 | 0 | 8 | 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 |
| 12-530 | M | 1920 | | 07 | 1958 | 364 | 1976* | 3 | B2 | 0.0 | Z9C | 1 | 0 | 2 | 0 |
| 12-532 | M | 1905 | | 17 | 1929 | 2132 | 1975 | 1 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 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 | 9 | 0 |
| 12-545 | F | 1920 | | 01 | 1937 | 902 | 1975 | 11 | B2 | 0.0 | Z9B | 3 | 0 | 25 | 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 | 18 | 0 |
| 12-553 | F | 1922 | | 01 | 1950 | 250 | 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 | 7 | 0 |
| 12-557 | F | 1919 | | 01 | 1936 | 676 | 1976* | 2 | B3 | 0.0 | Z9C | 1 | 0 | 6 | 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 | 1976* | 11 | B2 | 0.0 | Z9B | 3 | 0 | 29 | 0 |
| 12-583 | M | 1923 | | 08 | 1923 | 39 | 1976* | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 12-624 | F | 1939 | | 01 | 1965 | 312 | 1976* | 0 | B6 | 0.0 | Z9C | 0 | 0 | 0 | 0 |
| 12-656 | M | 1944 | | 01 | 1962 | 104 | 1976* | 2 | B2 | 0.0 | Z9C | 0 | 0 | 1 | 0 |
| 12-694 | F | 1931 | | 01 | 1949 | 13 | 1976* | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 12-709 | 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 |
| 12-746 | F | 1913 | | 01 | 1942 | 124 | 1976* | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 12-757 | F | 1922 | | 01 | 1941 | 104 | 1976* | 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 |
| 12-779 | F | 1929 | | 01 | 1952 | 52 | 1976* | 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 |
| 12-889 | F | 1924 | | 01 | 1947 | 260 | 1976* | 1 | B3 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 12-905 | F | 1914 | | 01 | 1949 | 312 | 1976* | 2 | B3 | 0.0 | Z9C | 0 | 0 | 3 | 0 |
| 12-908 | F | 1923 | | 01 | 1952 | 87 | 1976* | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |

TABLE 1 (CONT.) EXPOSURE DATA FOR RADIUM PATIENTS TO END OF 1976

| (1) CASE | (2) SEX | (3) BCRN | (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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12-943 | F | 1917 | | 01 | 1952 | 52 | 1976* | 1 | B6 | 0.0 | Z9C | 0 | 0 | 2 | 0 |
| 12-978 | F | 1919 | | 08 | 1919 | 39 | 1976* | 0 | B6 | 0.0 | Z9B | 0 | 0 | 0 | 0 |
| 12-983 | F | 1921 | | 01 | 1940 | 1040 | 1976* | 6 | B2 | 0.0 | Z9C | 1 | 0 | 12 | 0 |
| 12-985 | M | 1934 | | 08 | 1934 | 39 | 1976* | 1 | B6 | 0.0 | Z9B | 0 | 0 | 2 | 0 |
| 12-986 | M | 1932 | 1976 | 08 | 1932 | 39 | 1976* | 6 | B2 | 0.0 | Z9B | 2 | 0 | 15 | 0 |
| 13-007 | M | 1911 | | 67 | 1951 | 676 | 1976* | 1 | B6 | 0.0 | Z9B | 0 | 0 | 1 | 0 |
| 13-011 | F | 1924 | | 01 | 1942 | 39 | 1976* | 0 | G6 | 0.0 | Z9 | 0 | 0 | 0 | 0 |
| 13-015 | F | 1910 | | 01 | 1954 | 884 | 1976* | 1 | B6 | 0.0 | Z9C | 0 | 0 | 1 | 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 56 bone sarcoma cases and 29 sinus or mastoid carcinoma cases among the 1933 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 80 measured persons considered to have radium-induced malignancies. There is one more case (00-019) in Table 1 than appeared in the corresponding table in the 1976 annual report.[1] This case, previously listed among bone sarcomas in exposed persons with unknown or uncertain body content of radium, was exhumed and measured for radium body content in 1976. There are two more cases (01-087 and 03-676) in Table 2 than were listed in the corresponding table in the 1976 annual report. Case 01-087 had an epidermoid carcinoma, left ear polyp, diagnosed in 1957, and from a pathologic review of the radium cases in 1976,[2] it was concluded that this tumor probably arose in the left mastoid. Case 03-676 had an epidermoid carcinoma of the left mastoid diagnosed in 1976.

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.

Table 1. Bone Sarcomas in Persons with Known Radium Body Content as of 31 December 1976

| 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 |
| 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 | 9458 | 1960 |
| 01-562 | F | 1901 | 1931 | 1920 | 7143 | 1931 |
| 03-215 | M | 1896 | 1971 | 1925 | 6860 | 1957 |
| 01-031 | F | 1906 | 1934 | 1925 | 6824 | 1934 |
| 03-401 | F | 1900 | 1963 | 1923 | 6781 | 1962 |
| 00-005 | F | 1901 | 1939 | 1917 | 6643 | 1939 |
| 03-619 | F | 1903 | 1962 | 1922 | 6184 | 1962 |
| 01-007 | F | 1886 | 1949 | 1926 | 5972 | 1948 |
| 01-059 | F | 1905 | 1967 | 1920 | 5182 | 1962 |
| 01-011 | F | 1872 | 1937 | 1919 | 5175 | 1936 |
| 03-118 | F | 1898 | 1955 | 1931 | 5159 | 1955 |
| 00-007 | F | 1903 | 1935 | 1919 | 5046 | 1934 |
| 00-027 | F | 1902 | 1942 | 1918 | 4995 | 1942 |
| 03-429 | F | 1908 | 1976 | 1923 | 4387 | 1967 |
| 01-051 | F | 1904 | L | 1923 | 4265 | 1972 |
| 05-281 | F | 1898 | 1964 | 1916 | 4142 | 1956 |
| 03-234 | F | 1890 | 1965 | 1915 | 3810 | 1964 |
| 03-402 | F | 1905 | L | 1923 | 3761 | 1953 |
| 01-024 | F | 1901 | 1956 | 1919 | 3674 | 1956 |
| 01-179 | F | 1890 | 1966 | 1924 | 3642 | 1943 |
| 01-239 | F | 1901 | 1958 | 1917 | 3153 | 1955 |
| 01-520 | F | 1882 | 1969 | 1930 | 3132 | 1967 |
| 01-073 | F | 1900 | 1969 | 1921 | 3048 | 1969 |
| 01-099 | F | 1905 | 1945 | 1924 | 2923 | 1942 |
| 01-026 | F | 1905 | 1958 | 1925 | 2729 | 1955 |
| 03-649 | F | 1906 | 1954 | 1924 | 2664 | 1953 |
| 01-025 | F | 1886 | 1952 | 1924 | 2497 | 1950 |

Table 1. (contd.)

| CASE | SEX | BORN | DIED | EXPOSED | CUM.RADS | DIAGNOSED |
|---|---|---|---|---|---|---|
| 01-613 | F | 1906 | 1936 | 1923 | 2436 | 1936 |
| 03-212 | F | 1902 | 1951 | 1927 | 2412 | 1951 |
| 03-210 | M | 1906 | 1958 | 1926 | 2396 | 1956 |
| 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 |
| 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 1976

| 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 | L | 1921 | 10114 | 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 | L | 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 |
| 03-126 | F | 1910 | 1965 | 1931 | 3449 | 1965 |
| 01-573 | F | 1892 | 1945 | 1916 | 3307 | 1945 |
| 03-105 | M | 1903 | 1957 | 1931 | 3143 | 1957 |
| 03-423 | F | 1907 | 1972 | 1923 | 2036 | 1971 |
| 03-417[a] | 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 |
| 00-023 | F | 1900 | 1929 | 1917 | 1929 |
| 00-030 | F | 1903 | 1924 | 1918 | 1923 |
| 00-031 | F | 1903 | 1940 | 1921 | 1938 |
| 00-035 | F | 1900 | 1941 | 1917 | 1941 |
| 01-088 | F | 1906 | 1931 | 1923 | 1931 |
| 01-103 | F | 1903 | 1946 | 1922 | 1946 |
| 01-107 | F | 1909 | 1935 | 1923 | 1935 |
| 01-108 | F | 1908 | 1947 | 1924 | 1947 |
| 01-117 | F | 1907 | 1931 | 1922 | 1931 |
| 01-387 | F | 1895 | 1943 | 1918 | 1943 |
| 01-465 | M | 1881 | 1943 | 1925 | 1943 |
| 01-695 | F | 1908 | 1935 | 1923 | 1935 |
| 03-658 | F | 1903 | 1938 | 1922 | 1938 |
| 03-660 | F | 1907 | 1936 | 1923 | 1935 |
| 03-661 | F | 1906 | 1934 | 1922 | 1934 |
| 03-665 | F | 1909 | 1930 | 1924 | 1929 |
| 03-680 | F | 1906 | 1946 | 1924 | 1943 |
| 03-759 | F | 1904 | 1930 | 1924 | 1930 |
| 03-779 | F | 1905 | 1942 | 1922 | 1942 |
| 03-800 | F | 1908 | 1945 | 1924 | 1944 |
| 03-806 | F | 1896 | 1956 | 1922 | 1956 |
| 03-848 | F | 1903 | 1958 | 1922 | 1958 |
| 05-987 | F | 1901 | 1962 | 1918 | 1962 |
| 09-087 | M | 1891 | 1934 | 1912 | 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 |
| 03-675[b] | 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.

## Unmeasured Cases

Tables 3 and 4 list exposed persons with unknown or uncertain radium body content who had probable or confirmed bone sarcomas and probable or confirmed paranasal sinus or mastoid carcinomas, respectively. There are 26 probable or confirmed bone sarcoma cases and 5 probable or confirmed sinus or mastoid carcinoma cases among the approximately 1300 radium cases with unmeasured body burdens for whom medical data are available. We have evidence that 10 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. There is one less case in Table 3 than in the corresponding table of the 1976 annual report, case 00-019 having been transferred to the measured-case category (see Table 1).

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