COO-119-254

RESEARCH IN RADIOBIOLOGY

Annual Report of Work in Progress in the Internal Irradiation Program

Radiobiology Division

Department of Pharmacology

University of Utah College of Medicine

Building 522

Salt Lake City, Utah 84112

31 March 1979

Contract EY-76-C-02-0119

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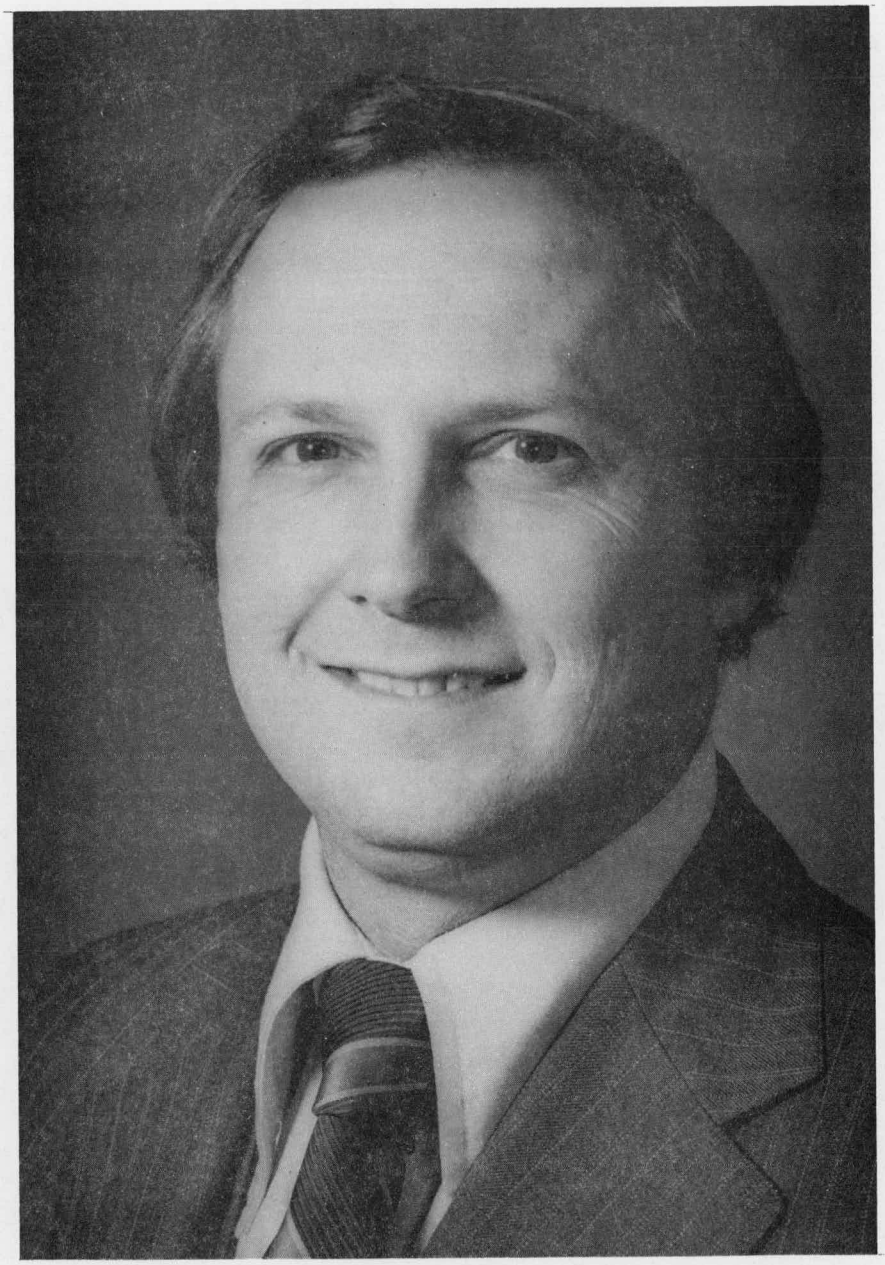

PROFESSOR McDONALD E. WRENN, DIRECTOR

In 1979 Professor McDonald E. Wrenn, from New York University Medical Center, became Director of the Radiobiology Laboratory, following Professor Webster S. S. Jee, who had served as Acting Director since the untimely death of Professor Thomas F. Dougherty in 1974. The Radiobiology Laboratory is now a Division of the Department of Pharmacology (Professor Dixon M. Woodbury, Chairman).

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GROUP LEADERS AND SECTIONS

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Department of Pharmacology
University of Utah College of Medicine

SECTION	
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Clinic and Pathology	Glenn N. Taylor
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STATUS OF THE BEAGLE COLONY*

as of 31 March 1979

NUCLIDE		NUMBER OF LIVING DOGS
^{253}Es	(Einsteinium)	6
^{252}Cf	(Californium)	30
^{249}Cf	(Californium)	24
$^{243/244}Cm$	(Curium)	0
^{241}Am	(Americium)	83
^{239}Pu	(Plutonium)	253
^{233}U	(Uranium)	1
^{228}Th	(Radiothorium)	0
^{228}Ra	(Mesothorium)	0
^{226}Ra	(Radium)	115
^{224}Ra	(Quickradium)	106
^{90}Sr	(Strontium)	0
Aging Controls		28
Unassigned		118
	TOTAL	764

*For detailed data, see the Appendix at the end of this report.

BONE SARCOMAS AT LOW DOSES OF α-RADIATION IN BEAGLES

Charles W. Mays, Glenn N. Taylor, Walter Stevens,
Webster S. S. Jee, and McDonald E. Wrenn

ABSTRACT: At low doses of α-particle radiation, the possibility of a linear dose response cannot be rejected by our present data on bone sarcoma induction by ^{239}Pu and ^{226}Ra in beagles.

The shape of the dose-response curve is very important in the correct assessment of risk from low doses of radiation. Three possibilities exist: *linear* (straight line), *concave upwards* (increasing slope with increasing dose), and *concave downwards* (decreasing slope with increasing dose). For bone sarcoma induction by low doses of densely ionizing α-particles, the dose response appears to be concave upwards for ^{226}Ra + ^{228}Ra in the U.S. radium dial painters[1] and for ^{228}Ra in beagles,[2] concave downwards for ^{224}Ra in mice,[3] and linear for ^{226}Ra in mice.[4,5] The following appear to be "approximately" linear (the linear possibility cannot be rejected statistically): ^{224}Ra in German patients,[2,6-9] ^{228}Th in beagles,[2] ^{239}Pu in rats,[10,2,5] ^{239}Pu in mice,[2,11] and ^{227}Th in mice.[3,2]

We are currently evaluating the induction of bone sarcomas in 176 young adult beagles injected with "low doses" of ^{239}Pu (Table 1 and Figure 1), and in 58 injected with "low doses" of ^{226}Ra (Table 2 and Figure 2). By low doses, we mean injections that are expected to produce a relatively low incidence of bone sarcomas, specifically 0.0007 to 0.016 μCi/kg of bone-surface-seeking ^{239}Pu, and 0.0074 to 0.062 μCi/kg of bone-volume-seeking ^{226}Ra. Animals sacrificed for special studies have been omitted from the analysis.

For each dose level, the ratio of bone sarcoma dogs/dead dogs is shown as a crude approximation of what the final incidence may become. When all of the dogs have died, the fraction with bone sarcomas will lie within the indicated limits. The lower limit would be reached if none of the living dogs develop bone sarcomas, whereas if all of the living dogs die with bone sarcomas, the upper limit would be attained. As the dogs continue to die, these limits will converge together at the final incidence. Since most of the dogs at the low levels are expected to die without bone sarcomas, the final incidence should usually be closer to the lower limit than to the upper.

Table 1. Bone sarcomas in low dose ^{239}Pu beagles (31 March 1979)

Injected (μCi ^{239}Pu/kg)	Injected Dogs	Living Dogs	Dead Dogs	Sarcoma Dogs	[Sar. Dogs / Dead Dogs] (%)	Av. skel. dose 10 yr post inj. (rad)
0.016	26	10	16	5	31	57
0.010	38	35	3	1	33	37
0.0055	38	27	11	3	27	20
0.0018	46	21	25	0	0	7
0.00070	28	15	13	1	8	3
Control*	133	35	98	1	1	0

*Young adult controls for ^{239}Pu, ^{226}Ra, ^{228}Ra, ^{228}Th, and ^{90}Sr.

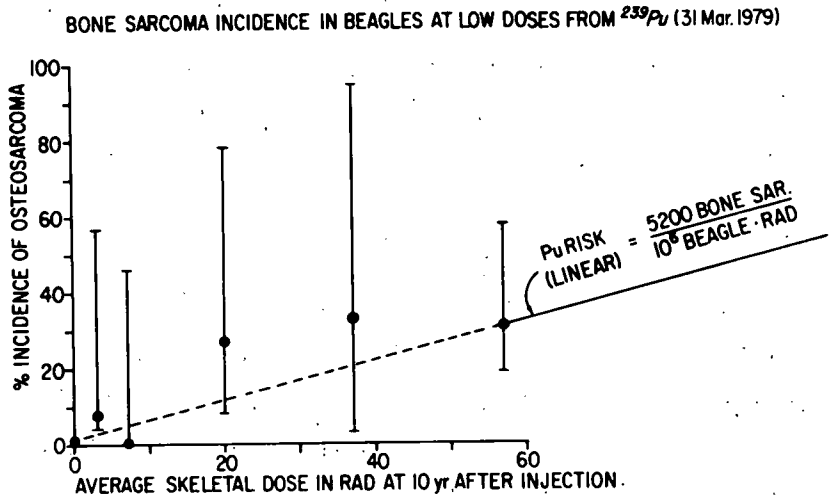

Figure 1. Bone sarcoma incidence in young adult beagles at low doses from ^{239}Pu. The ratio of bone sarcoma dogs/dead dogs, as of 31 March 1979, is plotted as a solid circle for each dose level. The final incidences, when all of the dogs have died, will be between the indicated upper and lower limits. Shown for comparison is the linear slope from our previously completed study in 28 beagles with plutonium doses from 55 to 135 rad, in which 14 developed bone sarcomas.[11] In the on-going low dose plutonium study, the possibility of a linear dose-response cannot be rejected by present data, although the final incidence might give a better fit to a concave downwards, or conversely, a concave upwards relationship.

Table 2. Bone sarcomas in low dose ^{226}Ra beagles (31 March 1979)

Injected (μCi ^{226}Ra/kg)	Injected Dogs	Living Dogs	Dead Dogs	Sarcoma Dogs	[Sar. Dogs / Dead Dogs] (%)	Av. skel. dose 10 yr post inj. (rad)
0.062	23	3	20	2	9	210
0.022	25	7	18	1	4	74
0.0074	10	2	8	0	0	25
Control*	133	35	98	1	1	0

*Young adult controls for ^{239}Pu, ^{226}Ra, ^{228}Ra, ^{228}Th, and ^{90}Sr.

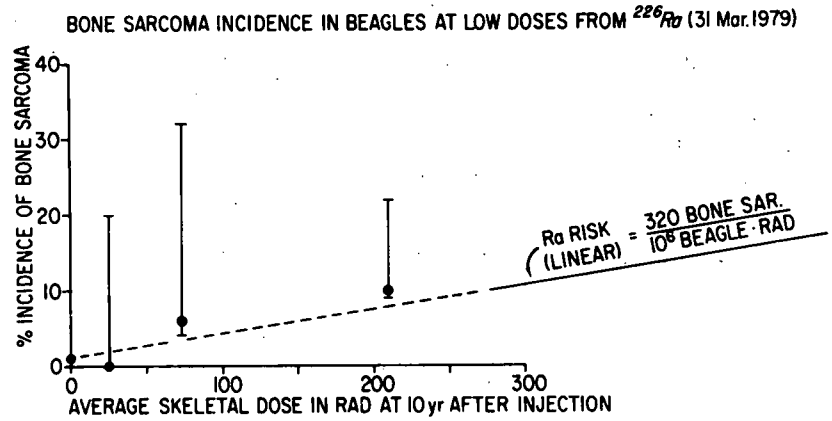

Figure 2. Bone sarcoma incidence in young adult beagles at low doses from ^{226}Ra. The ratio of bone sarcoma dogs/dead dogs, as of 31 March 1979, is plotted as a solid circle for each dose level. The final incidences, when all of the dogs have died, will be between the indicated upper and lower limits. Shown for comparison is the linear slope from our previously completed study in 51 beagles with radium doses from 183 to 2500 rad, in which 17 developed bone sarcomas.[11] In the on-going low dose radium study, the possibility of a linear dose response cannot be rejected by present data, although the final incidences might give a better fit to an alternative relationship.

Table 3. Bone sarcomas in low-level beagles (31 March 1979)

Nuclide	Dog	Injected μCi/kg	Years, inj. to death	Rads to skel. at death	Bone sarcomas
^{239}Pu	M1P1	0.0150	12.5	66	Osteosarcoma
	M3P1	0.0165	11.8	68	Osteosarcoma
	M8P1	0.0172	9.2	50	Osteosarcoma
	F9P1	0.0168	6.2	43	Osteosarcoma
	*F24P1	0.0163	9.1	55	Osteosarcoma
	*M15P0.7	0.00941	9.5	33	Chondrosarcoma (nasal cavity)
	F14P0.5	0.00493	12.4	21	Chondrosarcoma (nasal cavity)
	M19P0.5	0.00645	10.5	24	Osteosarcoma
	M36P0.5B	0.00527	10.6	20	Osteosarcoma
	F14P0.1	0.00055	12.3	2	Chondrosarcoma (humerus)
^{226}Ra	F19R1	0.0682	9.9	275	Osteosarcoma
	*M20R1	0.0610	11.7	324	Chondrosarcoma (nasal cavity)
	*F14R0.5	0.0220	13.9	102	Fibrosarcoma (mandible)
Control	*F13P0	0.000	14.7	0	Osteosarcoma

*Dogs dying with bone sarcomas during the past year.

These studies are still in progress and it will be some years before the final incidences are obtained. The present data are consistent with a linear dose-response, but do not exclude the possibility of a concave downward response, or for ^{239}Pu, a response that is slightly concave upward.

Much of the existing work on dose-response has been challenged because it was done with inbred rodents. Therefore, the studies in "outbred" beagles should have special relevance to the "outbred" human population.

Detailed information on the low dose animals with "bone" sarcomas (osteosarcomas, chondrosarcomas, and fibrosarcomas) is given in Table 3. Since our report of last year,[12] the first of our control beagles (F13P0) has died with a bone sarcoma 14.7 years after citrate injection (16.1 years of age at death).

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CHARACTERIZATION OF BONE-SURFACE CELLS IN A FATTY-MARROW, LOW TUMOR-INCIDENCE, TRABECULAR BONE SITE OF THE BEAGLE

S. C. Miller, M. M. Bowman, J. M. Smith and W. S. S. Jee

ABSTRACT: The purpose of this study was to characterize the surface density, morphology and ultrastructure of bone-surface "cells at risk" to radionuclides in a site of low radiation-induced osteosarcoma incidence. Particular attention was paid to the bone-lining cells which cover the majority of the trabecular surface. The numbers of osteoblasts, osteoclasts, and bone-lining cells were quantified on trabecular bone surfaces of 1μm-thick plastic sections of distal radii from control beagles of different ages. The average composite surface density of bone-lining cells was found to be about 450 cells/mm^2. Most of the lining cells had very flat, apparently disk-shaped, nuclei of about 10-15 μm in diameter and often less than 1μm in thickness. Cells with more oval or round nuclei were also encountered. The bone-lining cell nuclei were often found in areas containing capillaries bordered by fat cells. The cytoplasm of the lining-cells was often less than 0.1μm in thickness as it extended over the bone surface. Junctions which were morphologically similiar to Gap junctions (Macula Communicans) were frequently observed between adjacent bone-lining cell processes.

There appear to be many factors involved in the induction and location of occurrence of radionuclide-induced osteosarcomas. Most of the ^{239}Pu-induced osteosarcomas appear to originate in trabecular bone (Jee et al., '62). There is also a strong positive correlation between tumor frequency and trabecular bone area in the long bones of radium-induced and naturally occuring osteosarcomas in humans (Spiers et al., '77) and with ^{239}Pu- and ^{226}Ra-induced osteosarcomas in beagles (Jee, '78).

Another factor which appears to be important in osteosarcaoma induction is the rate of local bone turnover. Recently, Wronski and Jee ('79) have demonstrated in the beagle that trabecular bone turnover is greater in skeletal sites with a high incidence of osteosarcoma than in sites with a low incidence of osteosarcoma. They also demonstrated that these high osteosarcoma-incidence sites have a greater initial concentration of ^{239}Pu on bone surfaces as well as faster ^{239}Pu turnover than in low tumor incidence sites. It is also interesting to note that the high osteosarcoma incidence and high bone turnover sites are occupied with red bone marrow whereas the low tumor incidence and bone turnover sites contain fatty marrow (Wronski et

al., in preparation). Thus differences in the hematogenous milieu may have a direct influence on radionuclide deposition and local bone turnover rates and subsequent osteosarcoma induction.

In our attempts to further understand and predict the effects of radionuclides on osteosarcoma induction, it is necessary to characterize the "cells at risk" on bone surfaces. It is believed that proliferating bone-surface cells, irradiated by radionuclides deposited in the adjacent bone, are responsible for the development of osteosarcomas (Marshall and Groer, '77). The so-called bone-lining cells are capable of cell division (Kimmel and Jee, '78) and may have osteogenic potential and thus could represent a significant cell population "at risk" to radionuclides. Although the morphology and functional capacity of mature bone cells (osteoblasts, osteoclasts, and osteocytes) is quite well established, the surface density, morphology, and function of the bone-lining cell is not, even though these cells cover the majority of trabecular bone surfaces in the adult skeleton.

The purpose of this study is to describe the bone-surface cells with particular emphasis on the bone-lining cells found on trabecular bone surfaces from a fatty marrow, low radiation-induced tumor incidence site in the beagle.

MATERIALS AND METHODS

Distal radii from control beagles were obtained at routine autopsy. The distal radius contains fatty bone marrow and has a low incidence of radionuclide-induced osteosarcomas. The bones from these dogs were fixed in formalin, decalcified in EDTA, post-fixed in osmium tetroxide, stained *en bloc* in aqueous uranyl acetate and embedded in Epon 812 or Spurr's low viscosity plastic. One micron-thick sections with a block face of about 2mm x 3mm were cut on an ultramicrotome for light microscope cell counts and morphological evaluation. Thin sections (60nm - 90nm) were cut using glass or diamond knives and stained with uranyl acetate and lead citrate prior to examination in the transmission electron microscope.

For cell counts in the light microscope, the 1μm-thick plastic sections were stained with methylene blue - azure II - basic fuchsin (Humphrey and Pittman, '74). This complex stain was found to be very good in differentiating the very thin and flattened bone-lining cell nuclei from the adjacent bone surface. The numbers of osteoblasts, osteoclasts, and bone-

lining cells were counted and the total length of bone surface perimeter was measured at 400 X magnification using an eyepiece ocular Merz reticule. Two types of bone-lining cells were distinguished on the basis of their nuclear morphology; those having a more rounded or oval nucleus and those having a very flat nucleus. Any possible functional difference between these bone-lining cells is not established at this time.

RESULTS

Density of Bone Cells

The numbers of osteoblasts, osteoclasts, and bone-lining cells with rounded and flat nuclei per bone surface perimeter in the distal radii of control beagles are summarized in Table 1. Bone-lining cells with very flat nuclei are more frequently encountered than those with oval or rounded nuclei. At this time there appears ot be no significant difference in the numbers of lining cells between young adults and aging beagles. If both the flat and rounded bone-lining cell types are summed and averaged over the entire surface area, the surface density of these cells on trabecular bone of the distal radius is about 450 cells/mm^2. The numbers of mature osteoblasts and osteoclasts are considerably less than this.

TABLE 1. DENSITY OF BONE CELLS ON BONE SURFACES OF THE DISTAL RADIUS

		Lining Cells			
Age Range (days)	n*	Flat Nuclei no./mm ± S.D.	Round nuclei no./mm ± S.D.	Osteoblasts no./mm ± S.D.	Osteoclasts no./mm ± S.D.
362-585	3	15.9 ± 1.9	6.0 ± 0.9	2.9 ± 2.0	0.9 ± 0.2
2591-5878	7	15.3 ± 5.1	5.3 ± 2.4	0.5 ± 1.4	0.6 ± 0.4

*n = number of dogs used in each determination.

Light Microscope Observations

In the light microscope, bone-lining cells can only be recognized by their nuclei (Figs. 1 and 2), as the cytoplasm of these cells is usually too attenuated to be resolved. Cells with the very thin, flat nuclei are often in such close proximity to the bone surface that it is sometimes difficult to distinguish them from the densely stained lamina limitans found on many bone surfaces. Lining-cells containing rounded nuclei are easier to distinguish because of their shape. The bone-lining cells, particularly those with the more rounded nuclei, are frequently found in triangular-shaped areas bordered by adjacent fat cells and the bone. Capillaries are frequently seen in these areas (Fig. 1).

Electron Microscope Observations

In the transmission electron microscope a more accurate determination of nuclear size, proximity to bone surfaces, and nuclear and cellular morphology can be made. In the example illustrated in Figure 3, this flat nucleus of a bone-lining cell is about 13μm in length and from 0.5 - 1.0μm in width. The nucleus is about 1μm away from the lamina limitans which may represent the true mineralization front (Miller, unpublished observations). These dimensions are generally typical for the bone-lining cells with flattened nuclei.

Examination of bone-lining cells by electron microscopy confirms that nuclei are often found in triangular-shaped regions formed by adjacent fat cell membranes and the bone surface (Fig. 4). The lining-cell nuclei are often found in areas of vascular capillaries (Fig. 4). Most of the lining-cells have extensive, yet very thin, layers of cytoplasm extending over the bone surface (Figs. 5, 6, and 7). The cell cytoplasm is often only from 50 - 100nm in thickness and cell processes can be seen extending into canaliculi in the bone matrix (Fig. 6). Cell junctions are frequently found between adjacent cell processes or cell layers (Fig. 7). At greater magnifications the cell junctions appear similiar to Gap junctions (also called nexus or macula communicans).

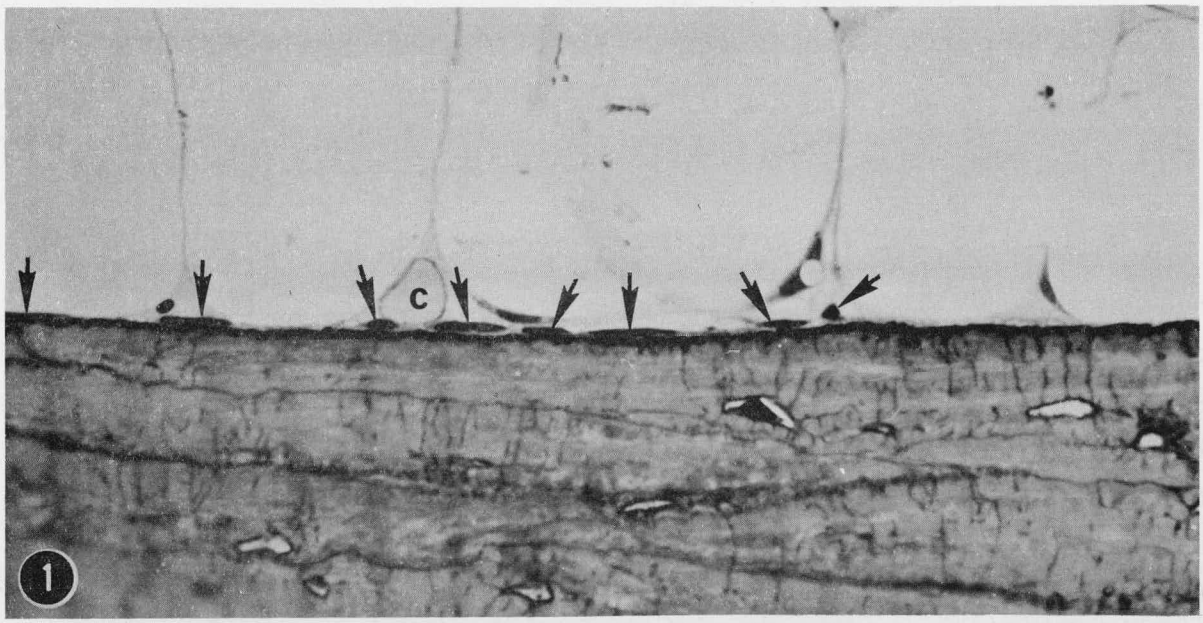

FIGURE 1. Light micrograph of a 1µm-thick plastic section of a bone spicule from the distal radius of a beagle. The nuclei of bone lining cells can be seen extending along the bone surface (arrows). A small capillary adjacent to the bone can also be seen (C). 1,500 X.

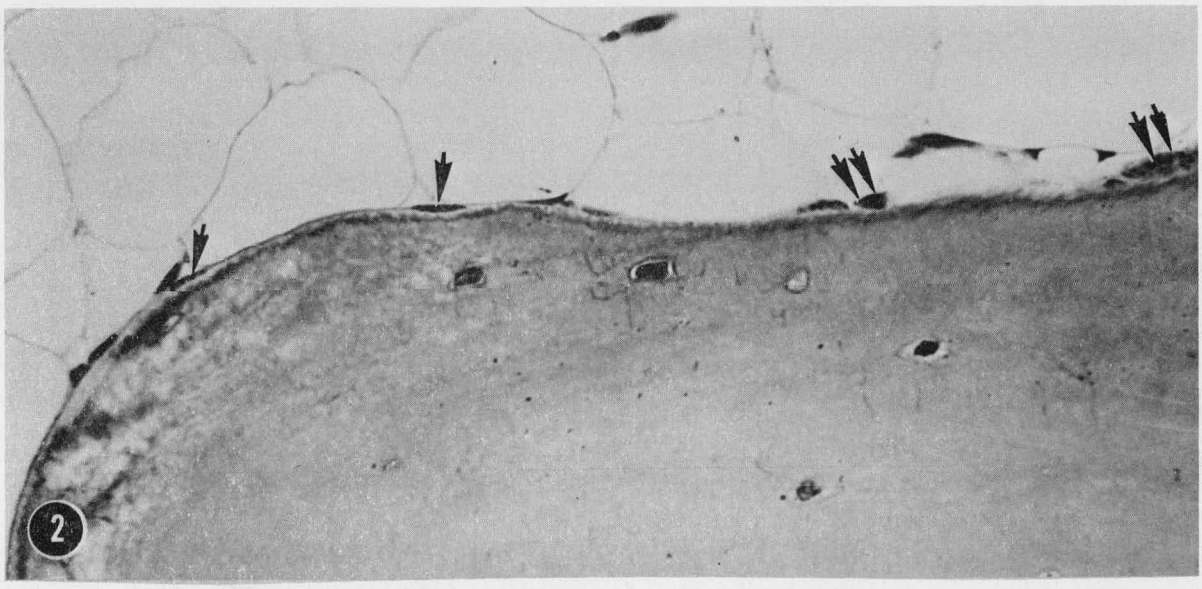

FIGURE 2. This light micrograph illustrates the two types of bone-lining cells that were quantified in this report. Some lining cells have very flat nuclei (single arrows) and others have more rounded or oval shaped nuclei (double arrows). 1,500 X.

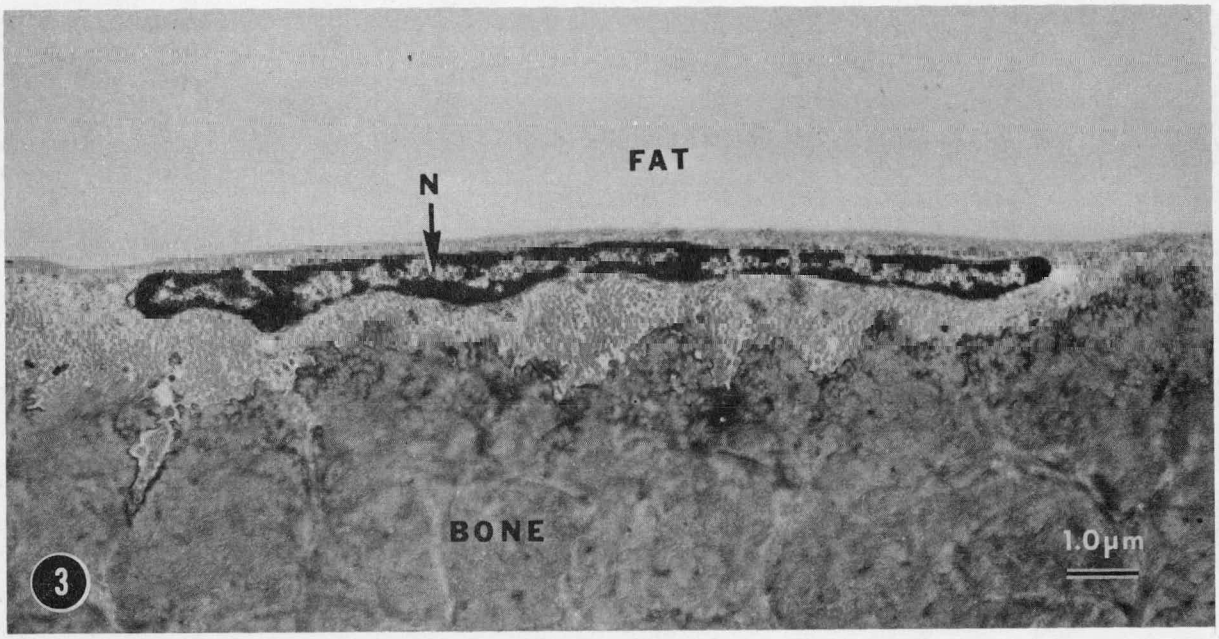

FIGURE 3. Transmission electron micrograph of a flat nucleus (N) of a bone-lining cell. 9,100 X.

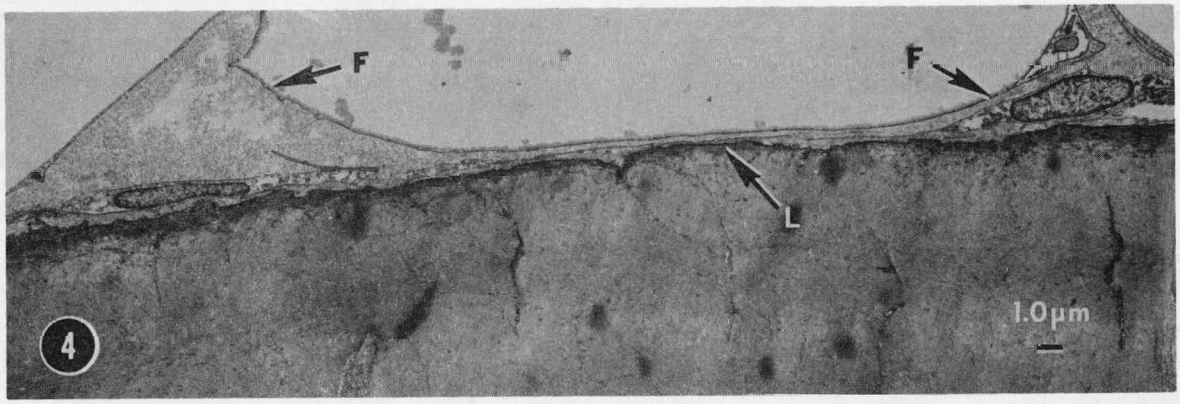

FIGURE 4. Low power electron micrograph of bone-lining cells extending along a bone surface. The nuclei of the lining cells are found in triangular-shaped regions bordered by the fat cell membranes (F) and the bone. Lamina limitans (L). 3,400 X.

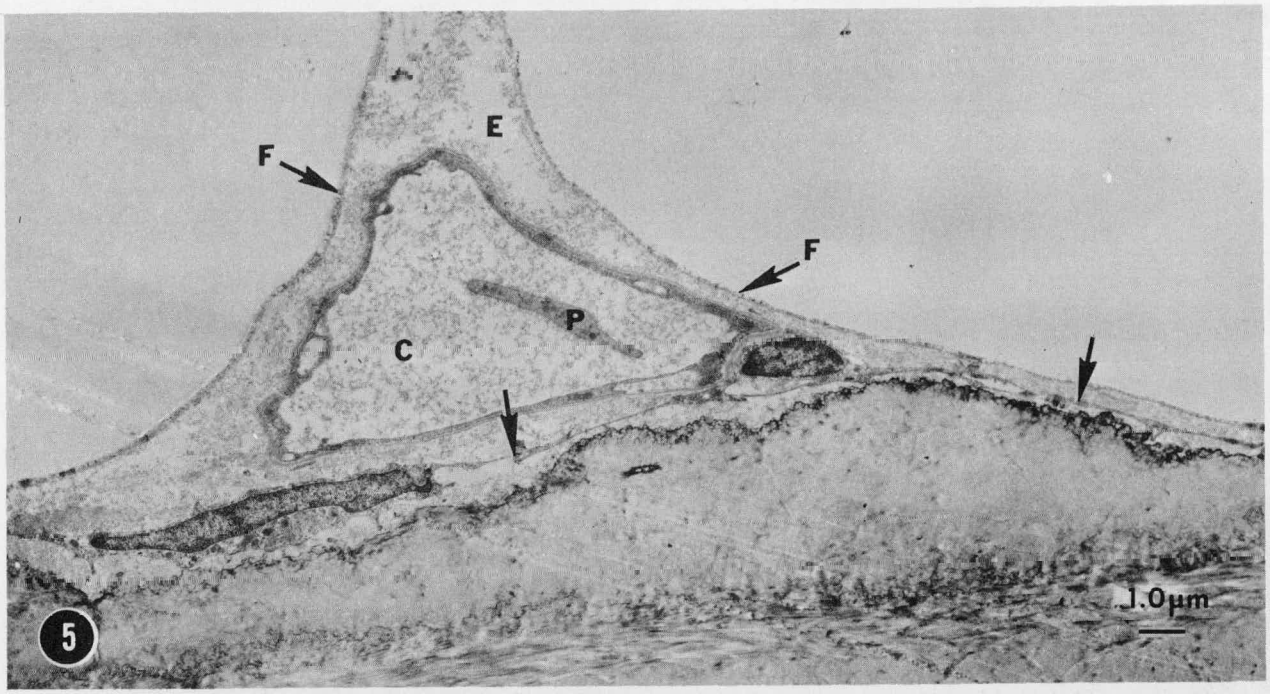

FIGURE 5. Electron micrograph of several bone-lining cells with their nuclei in close proximity to a capillary (C). The cytoplasm of the lining cells (arrows) can be seen extending along the bone surface. E, endothelium. P, blood platelet. F, fat cell membrane. 5,500 X.

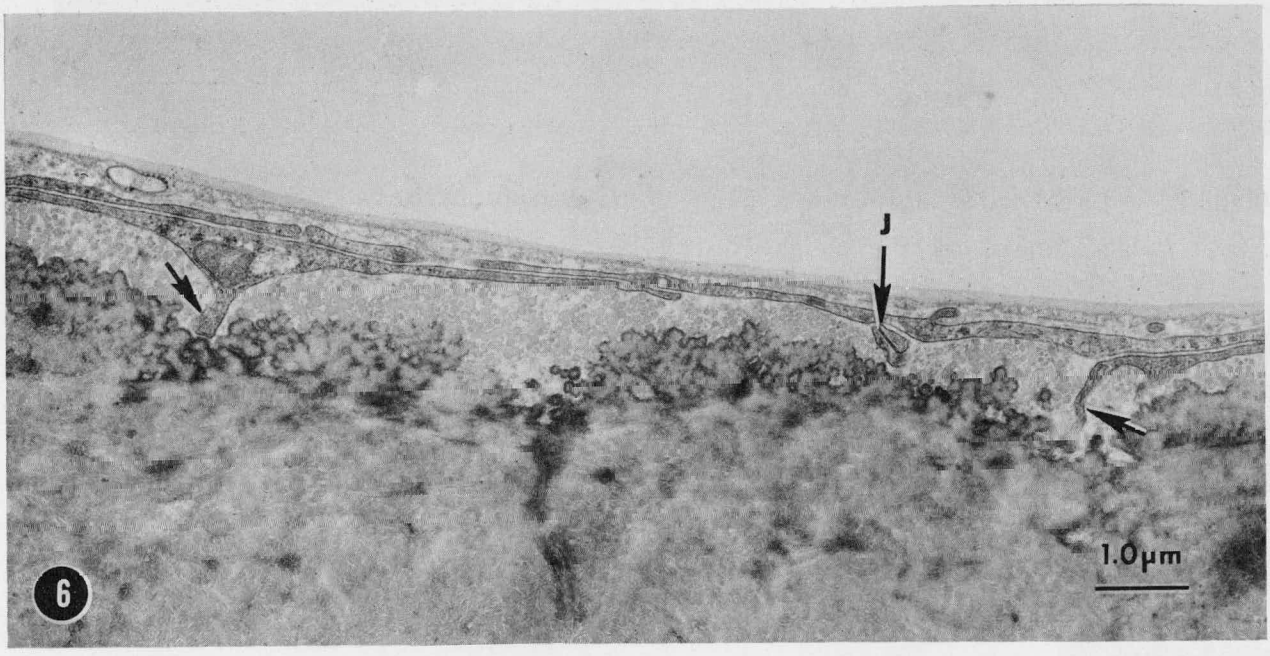

FIGURE 6. Greater detail of the thin lining cell cytoplasm covering bone surfaces. An occasional cell process appears to extend into the bone matrix (arrows) and small junctions (J) can be seen between cell processes. 11,800 X.

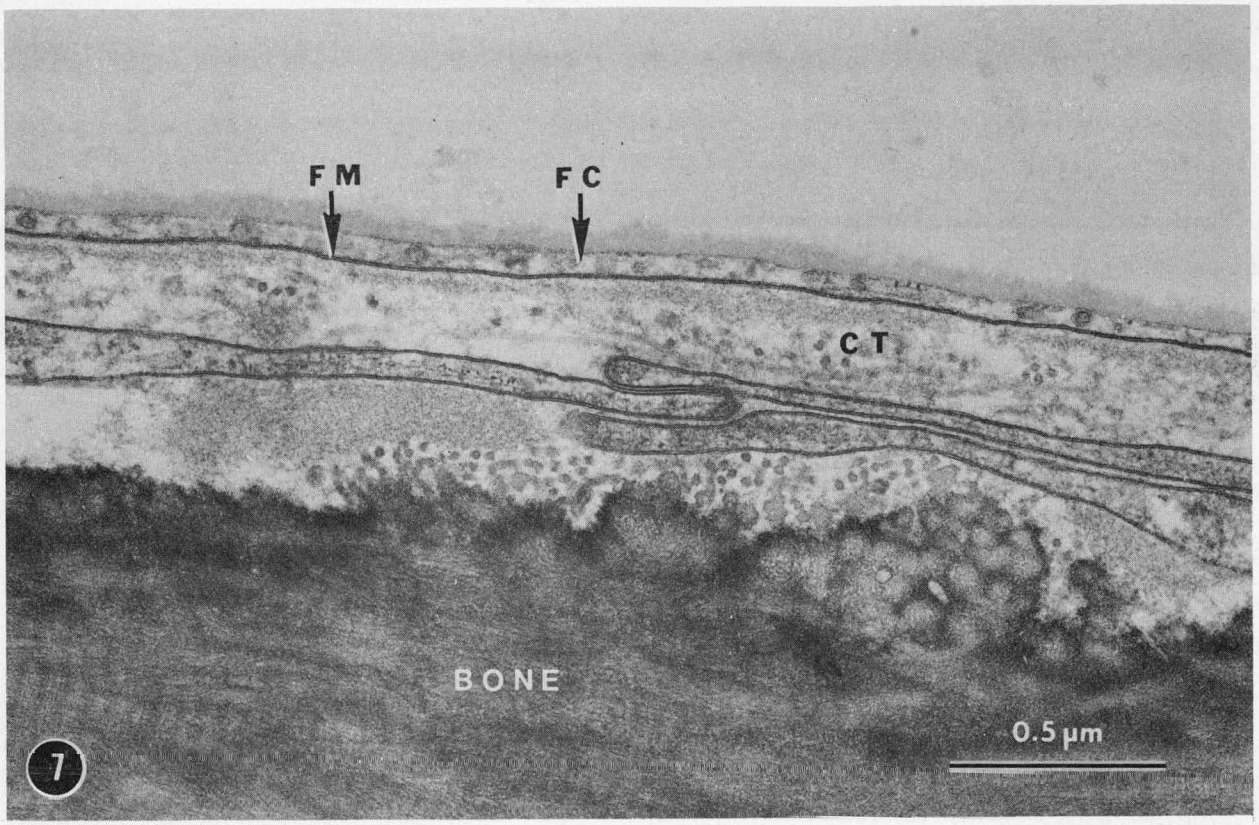

FIGURE 7. Greater detail of a typical junction found between bone-lining cells. These junctions are morphologically similiar to Gap junctions. The fat cell membrane (FM) and a thin rim of the cytoplasm of this cell (FC) is well seen in this micrograph. Between the bone-lining cell and the fat cell there is some loose connective tissue (CT) containing prominent collagen fibers. 54,400 X.

DISCUSSION

This report presents preliminary findings on the density, morphology and ultrastructure of bone-lining cells in a low radiation tumor incidence, fatty marrow trabecular bone site. This study demonstrates that bone-lining cells have an overall surface density of about 450 cells/mm^2. The nuclei of the the bone-lining cells can be either oval, occasionally round, or more frequently, very flat. The flat nuclei of lining cells appear to be flat disks having a diameter from 10 - 15μm and often less than 1μm in thickness. It appears that the nuclei are generally about 1.0μm from the lamina limitans. Further work is in progress to define more precisely the proximity of the lining cell nuclei to the actual mineralization surface. This information is necessary for more precise calculations of dose rates to bone cells for radionuclides deposited in and on bone.

The nuclei of bone-lining cells are not, however, uniformly distributed on bone surfaces. The nuclei are often found adjacent to capillaries between fat cells and the very thin cytoplasm of the bone-lining cells extends over the bone surface. Further work is in progress to define more precisely the relationships of bone-lining cells and the blood vascular system. This information is important not only for our understanding of bone biology, but may provide some insights into the observed differences in ^{239}Pu incorporation and turnover at these sites compared to red bone marrow-bone sites (Wronski et al., in preparation).

One unexpected finding in this study is the common frequency of cell junctions between lining cells. These junctions appear morphologically similiar to Gap junctions (McNutt and Weinstein, '73). However, to confirm that these are, in fact, true Gap junctions will require additional ultrastructural tracer and freeze-fracture studies. Occluding junctions, like tight junctions or Zonula Occludens, were rarely, if ever, found between adjacent lining cells.

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ON THE CALCULATION OF TRABECULAR BONE FORMATION RATES FROM TETRACYCLINE LABELING DATA

J. M. Smith

ABSTRACT: In calculating trabecular bone formation rates from the data provided by tetracycline labeling, the question arises as to what to use for the fraction of surface actively forming (S_{act}) during the labeling period. It is shown that if one can assume that all osteoid is active, then S_{act} is given by the sum of the fraction of surface with a double-label of tetracycline and 1/2 of the fraction of surface with a single-label.

Introduction

Conventionally, one uses the tetracycline-based histological analysis of Frost (1969) for determining skeletal turnover in a mature (remodeling) skeleton. The purpose of this paper is to derive a formula for the calculation of trabecular bone formation rates ($^{V}V_f$) from the data provided by the tetracycline labeling procedure. For the purposes of the present work, we assume that all osteoid is active; a good approximation in the case of the young adult beagles within the Radiobiology Laboratory's beagle colony.

Methods

Conventionally, $^{V}V_f$ for trabecular bone is calculated by the following equation:

$$^{V}V_f = MS_{act}(S/V)_{trab} \qquad (1)$$

where M is the appositional rate, S_{act} is the fraction of trabecular surface actively forming and $(S/V)_{trab}$ is the specific bone surface to volume ratio for trabecular bone. The question arises as to the determination of S_{act} from the tetracycline data. The latter is typically provided as fraction of surface with a single label ($^{SL}S_{act}$) and fraction with double label ($^{DL}S_{act}$). Both the sum of these values and the fraction of surface with double label only have been used widely in the literature for S_{act}.

Let us consider the concept of the "bone metabolic unit" (BMU) proposed by Frost (1969). Let,

$$^{v}V_f = n_{BMU} \frac{dB}{dt} \tag{2}$$

where n_{BMU} is the number of BMU's per unit volume of existing bone (number per mm^3) and $\frac{dB}{dt}$ is the rate at which a BMU forms bone $(\frac{mm^3}{day})$. $^{v}V_f$ is then in the proper units of mm^3 of new bone formed per mm^3 of old bone per day.

The fraction of new bone formed during the marker interval (time between labels of tetracycline, measured from the middle of the first labeling period to the middle of the second) would, therefore, be given by

$$\beta \equiv {}^{v}V_f\ (MI) = n_{BMU}\ (\frac{dB}{dt})(MI), \tag{3}$$

<u>if</u> all BMU's were actively forming during the marking interval (MI = marker interval).

However, not all of the BMU's engaged in laying down new bone (at rate $\frac{dB}{dt}$) do so continually. Those which yield a double-label do; those which have escaped double-labeling, giving only a single-label, have escaped because they are not working continually throughout the marker interval.

The parameter β can be divided into 2 parts: $^{DL}\beta$ (the amount of new bone formed per unit volume due to BMU's which give rise to double labels) and $^{SL}\beta$ (the counterpart for single-labeling) where,

$$\beta = {}^{DL}\beta + {}^{SL}\beta\ . \tag{4}$$

Expressions for $^{DL}\beta$ and $^{SL}\beta$ can be readily obtained by reference to the "Frost ladder" (Fig. 1).

The purpose of the Frost ladder is to conceptulize the temporal relationship among the BMU's within a volume of bone. Each "rung" of the ladder represents an individual BMU and the length of the rung is equal to its duration (σ_f). Note that conventionally the BMU's are arranged in order of increasing initiation times.

In Fig. 1 the total volume of new bone laid down per unit volume of old bone is represented in region II where, by analogy with equation (3),

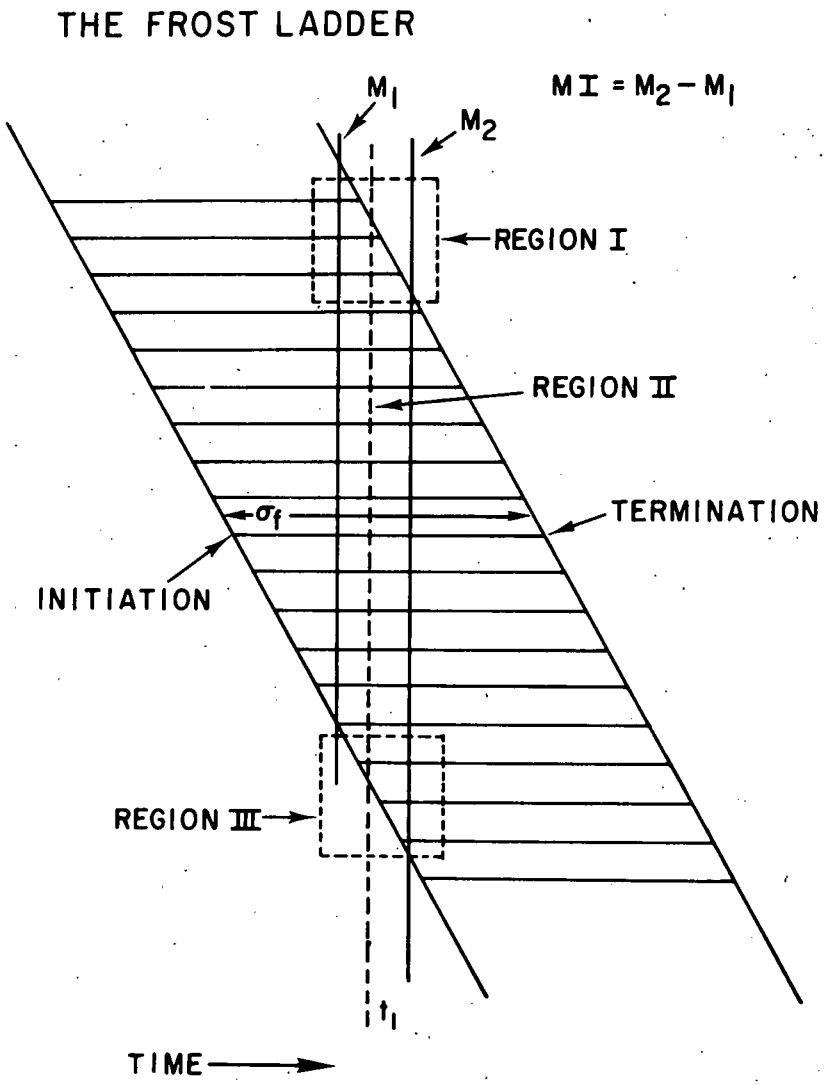
THE FROST LADDER
M_1
M_2
$MI = M_2 - M_1$
REGION I
REGION II
σ_f
TERMINATION
INITIATION
REGION III
t_1
TIME

FIGURE 1.

$$DL_{\beta} = DL_{n_{BMU}} \left(\frac{dB}{dt}\right)(MI) \tag{5}$$

and, in this case, $DL_{n_{BMU}} = 11$. This equation states that the amount of bone laid down per unit volume during the marking interval is due to each BMU in region II laying down bone at the constant rate $\frac{dB}{dt}$ for the duration of the marking interval (MI).

Let us now derive an expression for SL_{β}. Note that $SL_{n_{BMU}}$ is given by the sum of those BMU's in region I and those in region III. We will designate the former by $T_{n_{BMU}}$ and it is equal to the number of BMU's per unit volume which have "terminated" during the marking interval (region I). The latter will be designated $I_{n_{BMU}}$ and is equal to the number of BMU's per unit volume which have been "initiated" during the marking interval (region III; they terminate after the marking interval). Note that,

$$SL_{n_{BMU}} = T_{n_{BMU}} + I_{n_{BMU}}, \tag{8}$$

In a state of dynamic equilibrium,

$$T_{n_{BMU}} = I_{n_{BMU}}, \tag{9}$$

i.e., for every BMU terminating during the marking interval, there is one which is initiated. (In the diagram, $T_{n_{BMU}} = I_{n_{BMU}} = 3$.)

It is readily seen from the ladder diagram that the average time in which either a terminating or initiating BMU works forming bone during the marker interval is 1/2 MI. (The BMU's which give rise to double labeling, on the other hand, work continually throughout the marker interval, and their "average working time" is exactly MI.)

Therefore, the volume of the new bone laid down per unit volume of old bone during the marking interval by terminating BMU's (region I) is given by

$$T_{n_{BMU}} \left(\frac{dB}{dt}\right)\left(\tfrac{1}{2}\ MI\right) \tag{10}$$

and, likewise, from region III,

$$I_{n_{BMU}} \left(\frac{dB}{dt}\right)\left(\tfrac{1}{2}\ MI\right) . \tag{11}$$

The sum of the terms (10) and (11), therefore, represents bone formation due to "escape" or single-label BMU's:

$$SL_\beta = {}^{T}n_{BMU} \left(\frac{dB}{dt}\right)\left(\tfrac{1}{2}\ MI\right) + {}^{I}n_{BMU} \left(\frac{dB}{dt}\right)\left(\tfrac{1}{2}\ MI\right)$$

$$= \left({}^{T}n_{BMU} + {}^{I}n_{BMU}\right) \frac{dB}{dt} \left(\tfrac{1}{2}\ MI\right) \qquad (12)$$

Note that since, $SL_{n_{BMU}} = {}^{T}n_{BMU} + {}^{I}n_{BMU}$,

$$SL_\beta = \frac{dB}{dt}\ (MI)\left(\tfrac{1}{2}\ SL_{n_{BMU}}\right) \qquad (13)$$

Another way to arrive at the same conclusion is to note that for every BMU which terminates at a given time (t_1, say) during the marker interval, there is one which is initiated. Therefore, in a conceptual way we can think of the single-labeling BMU's working continually throughout the marker interval, provided that we use 1/2 of the total number of initiating and terminating BMU's.

All of the above still holds true as one mixes vertically the rungs of the Frost ladder and simultaneously allow their lengths to vary. This would represent a more accurate view of the situation as it occurs in nature.

Combining equations (4), (5), and (13) we have:

$$\beta = DL_\beta + SL_\beta$$

$$= DL_{n_{BMU}} \left(\frac{dB}{dt}\right)(MI) + \left(\frac{dB}{dt}\right)(MI)\left(\tfrac{1}{2}\ DL_{n_{BMU}}\right)$$

and, therefore,

$$\beta = \left(\frac{dB}{dt}\right)(MI)\left[DL_{n_{BMU}} + \tfrac{1}{2}\ SL_{n_{BMU}}\right]. \qquad (14)$$

However, from our definition of β in equation (3) ($\beta \equiv {}^{v}V_f \cdot MI$) we can change equation (14) to:

$${}^{v}V_f = \left(\frac{dB}{dt}\right)\left[DL_{n_{BMU}} + \tfrac{1}{2}\ SL_{n_{BMU}}\right] \qquad (15)$$

by dividing both sides by MI. This equation then shows us how to divide the total bone formation rate, ${}^{v}V_f$, into 2 separate components: one for those

BMU's responsible for double-labeling, and the other for those responsible for single labeling. Note the weighting factor of 1/2 for "single-labeling BMU's."

At this point, let us return to the general equation (2):

$$^{v}V_f = n_{BMU} \frac{dB}{dt} \tag{2}$$

The rate at which a BMU lays down new bone is a constant, $\frac{dB}{dt}$ (proportional to M, the appositional rate). Let's consider the BMU's which give rise to a double-label during the marking interval. Their number per unit volume is $^{DL}n_{BMU}$, and (2) follows immediately. The equivalent way of expressing this rate is

$$^{DL}n_{BMU} \frac{dB}{dt} = M \, ^{DL}S_{act} \, (S/V)_{trab} \tag{16}$$

The right hand side of this equation is the product of the appositional rate (M), the surface-to-volume ratio of trabecular bone $(S/V)_{trab}$, and the fraction of trabecular surface area which takes a double label. ($^{DL}S_{act}$ is, using Frost's symbols, $S_{fract(lab)}$, with the constraint of double-labels only.)

The bone formation rate for those surfaces which take only a single label is, in general, different and would be expressed as follows:

$$^{SL}n_{BMU} \frac{dB}{dt} = M \, ^{SL}S_{act} \, (S/V)_{trab} \tag{17}$$

where $^{SL}S_{act}$ is that fraction of the trabecular surface which takes only a single label. Note that although an <u>individual</u> BMU always "works" at the rate $\frac{dB}{dt}$, the <u>amount</u> of bone formed during the marker interval is different for those BMU's which work continually throughout the marker interval (giving double-labels) as opposed to those which terminate or are initiated during the marker interval (giving rise to single-labels). The ratio in the number density of these respective BMU's is found by dividing equation (16) by (17):

$$\frac{^{DL}n_{BMU}}{^{SL}n_{BMU}} = \frac{^{DL}S_{act}}{^{SL}S_{act}} \tag{18}$$

As we would expect, this ratio is merely the ratio of double-labeled surface fraction to single-labeled surface fraction.

We are now ready to use equation (15); let us substitute equations (16) and (17) into that equation. The result is:

$$^{v}V_f = M\ ^{DL}S_{act}\ (S/V)_{trab} + \tfrac{1}{2}\ M\ ^{SL}S_{act}\ (S/V)_{trab} \qquad (19)$$

or,

$$^{v}V_f = M\ S_{act}\ (S/V)_{trab} \qquad (20)$$

where,

$$S_{act} = {}^{DL}S_{act} + \tfrac{1}{2}\ {}^{SL}S_{act}\ . \qquad (21)$$

Conclusion

In calculating trabecular bone formation rates, using tetracycline labeling, the investigator should ascertain the fraction of trabecular surface with a single label ($^{SL}S_{act}$) of tetracycline, and the surface fraction with a double-label ($^{DL}S_{act}$). If it can be assumed that all osteoid is actively forming (a good assumption for young adult beagles), then one can calculate the rate of bone formation ($^{v}V_f$) by equation (1) in the text:

$$^{v}V_f = M\ S_{act}\ (S/V)_{trab}\ , \qquad (1)$$

where M is the corrected appositional rate, $(S/V)_{trab}$ is the trabecular surface to volume ratio, and S_{act} is given by

$$S_{act} = {}^{DL}S_{act} + \tfrac{1}{2}\ {}^{SL}S_{act}\ .$$

Acknowledgments

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MEASUREMENT OF SOME CHARACTERISTICS OF TRABECULAR BONE OF HUMERUS, LUMBAR VERTEBRAE, AND CALVARIUM, AND OF CORTICAL BONE OF HUMERUS OF ADULT RHESUS MONKEY (*Macaca mulatta*)

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ABSTRACT: We report here a cooperative quantitative study of trabecular bone structure of the proximal humerus, lumbar vertebra, and parietal bone of the skull, and cortical bone of the humeral diaphysis of six male and six female rhesus monkeys in young adulthood (6.5 to 15 yr), and of eight female monkeys which were middle-aged to senile (18 to 31.5 yr). Microradiographs of ground bone sections were analyzed by a Quantimet 720 Image Analyzer. Parameters of importance to radiation dosimetry - bone surface to volume, fractional bone volume or porosity, and trabecular size - were measured.

The fractional bone volume for the trabecular region of the calvarium was about a factor of two higher than that for the proximal humerus or vertebra. The surface/volume ratio was greater in the metaphysis than in the epiphysis, due to thicker trabeculae within the latter region. Only two statistically significant differences were found between the parameters of the males and females of comparable age. The mean trabecular chord in the lumbar vertebrae of the males was larger (and the surface/volume, smaller) than of the females. In the bones of both sexes the percent bone volumes were the same, suggesting a larger number of trabeculae in the vertebrae of the females.

Trends in the data are discussed along with comparative studies in the dog and man by other authors.

Introduction

The late biological effects (chiefly tumors of skeletal tissue) elicited by several important bone-seeking radionuclides are the focus of research at this Laboratory. Recently, methods have been devised here and elsewhere that permit the quantitative estimation of local radiation doses to the critical

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cells of the skeleton of man (1,2,3) and of the best studied experimental animal, the Beagle dog (8). Because of the close phylogenetic relationship between man and the higher order non-human primates (apes and Old World monkeys), it was appropriate to extend such measurements to the skeleton of the rhesus monkey (*Macaca mulatta*). These measurements serve two important purposes: first, to define the similarities and differences in the morphometry (sizes, shapes, amounts) of the bony structures of adult man and skeletally mature, long-lived laboratory animals, and second, to examine the trends of skeletal morphometry both between the sexes and as functions of advancing age. Beddoe (4) reported measurements of several trabecular structures of one rhesus monkey of unspecified sex, age or body size (from the illustrations it would appear that the monkey may not have been skeletally mature).

We report here a cooperative quantitative study of trabecular bone structure of proximal humerus, lumbar vertebra, and the parietal bone of the skull, and the cortical bone of the humeral diaphysis of six male and six female rhesus monkeys in the prime of young adulthood (6.5 to 15 yr), and of eight female monkeys that were middle-aged to senile (18 to 31.5 yr).

Materials and Methods

The control bone material was obtained from the caged colony at the Dept. of Obstetrics and Gynecology, Medical School, Yale University. The animals, all *Macaca mulatta*, were of known age. They were either born in captivity or were received from the wild before skeletal maturity, and birth dates ± 3 mo could be determined from two sets of skeletal roentgenograms taken 6 mo apart. When animals in that colony died, they were autopsied and the eviscerated carcasses were packed in ice and shipped by air to the Lawrence Berkeley Laboratory. The entire control collection consists of 38 animals as follows: 31 female, six 6 to 10 yr old, seventeen 11 to 20 yr old, eight 21 to 32 yr old; seven male, five 6 to 10 yr old, two 11 to 15 yr old. The present series of bone specimens includes material from the seven males, seven of the eight females more than 20 yr old, and for each of the two groups of younger female monkeys the three whose total skeletal ash weights were closest to the means of their respective groups. The identification numbers and ages of the individual animals are given in Tables of data (1 to 5).

Soft tissues were scraped from the bones with sharp blades, and the fresh and ashed weights of all skeletal parts were recorded. Several bone specimens were preserved for histological study in 80% alcohol (right humerus, one-half of the calvarium, and the first lumbar vertebra). Slabs, 3 to 4 mm thick, were cut from those bones with a jeweler's saw as follows: humerus -- central a-p longitudinal section of proximal epiphysis and metaphysis (Fig. 2) and a cross-section of the central diaphysis; L1 vertebral body -- central a-p longitudinal section (see Beddoe, 1978, Fig. 2d); calvarium -- a-p section cut 5 mm to the right of center from behind the orbit to the occipital bone articulation, thus the sample measured included frontal and parietal bone (Fig. 5). The bone slabs were dehydrated in alcohol and embedded in Bioplastic (Ward's Scientific Establishment, Monterey, Calif.). Sections, 300 to 400 μm thick, were cut from the blocks with a rotary diamond saw, and these were hand ground to 100 μm between glass plates using size 30 μm Al_2O_3 grit in water. The thin sections were labeled and shipped to the Radiobiology Laboratory.

The ground sections were x-rayed (Machlett C-529A type A-2 diffraction tube) for one minute and 15 seconds at 12 kV and 25mA on 25 x 75 mm Kodak spectroscopic plates (type 649-0, Eastman Kodak Co., Rochester, NY). The microradiographs were standardized by a step wedge made from layers of 100 μm thick aluminum foil. The standard was three layers of aluminum foil giving a microradiograph with an optical density of 0.80 ± 0.1 (5). The microradiographs were then analysed by a Quantimet 720 Image Analyzer (QTM)(Cambridge-Imanco, Monsey, NY) as described in the next section.

The QTM derives numerical data from images produced by a television scanner (Plumbicon^R) interfaced to a Reichert Zetopan microscope with transmitted illumination. The automatic stage of the microscope provides X, Y, and Z (focussing) movements of the microradiographs. Feature detection is performed manually using gray level contrast. The System has an image editor module which allows the operator to specify particular regions or reject unwanted regions of the image for measurement, using a light pen to trace the region on the display screen.

The measurements in the present work were made with the QTM System interfaced to a programmable HP9810A calculator and standard teletype. A block diagram of the system is shown in Fig. 1.

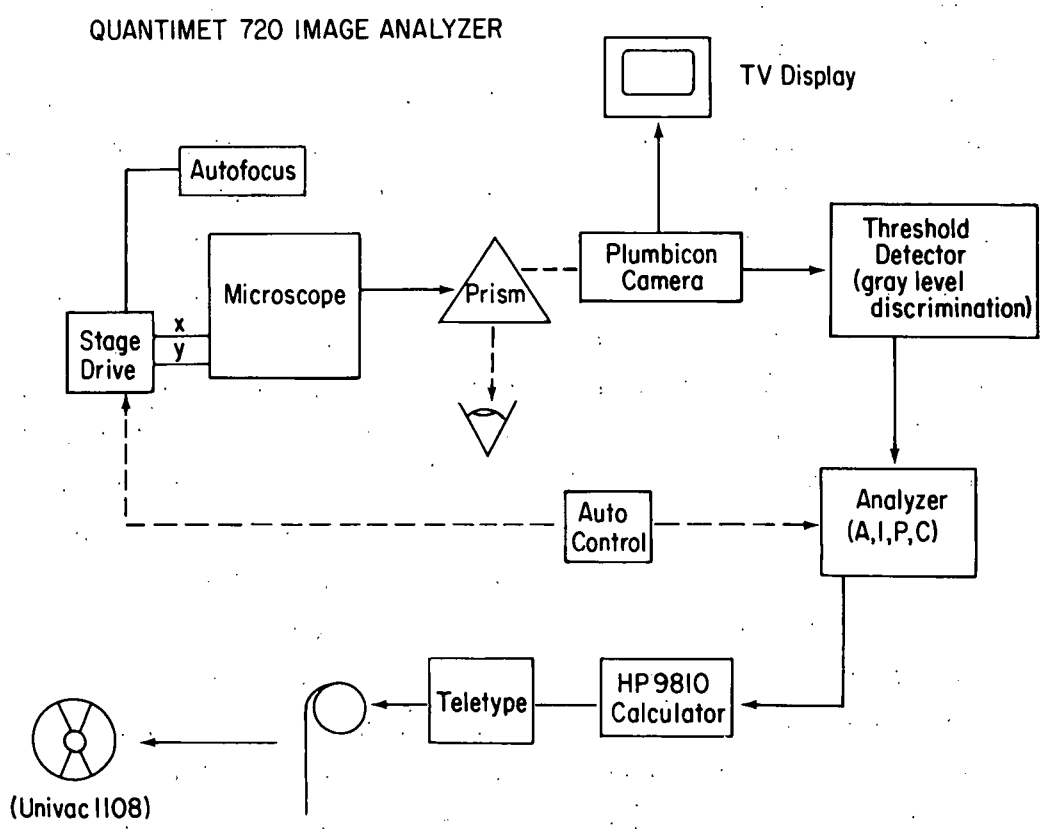


FIGURE 1. Quantimet 720 Image Analysis System.

Measurements

1. Proximal Humerus (Trabeculae)

Microradiographs of longitudinal sections from the proximal humerus of the monkey were prepared as described above. Two and sometimes three pieces make up a complete section of the proximal portion of the humerus and they were evaluated together. This is illustrated in Fig. 2.

In performing measurements on these microradiographs with the Quantimet 720 (QTM), the cortex was eliminated from analysis using the image editor module of the QTM, and only the trabecular bone was included in the data. A program (BONE/MARROW PARAMETERS, Nov. 1, 1977) yielded the data (units of mm or mm^2) shown in the sample readout below:

BONE (units of mm)

Area (A)	Intercept (I)	Perimeter (P)	P/A	A/I	Percent Bone
5.2244	30.7207	89.2252	17.0785	Ø.1701	23.5979

P/A [MARROW] is 5.2750 A/I [MARROW] is Ø.5335

A 1X objective was used with a total optical magnification of 10X.

Surface to volume ratio (S/V), fractional bone volume (percent bone), and mean trabecular chord were calculated from the data. The values for these three parameters appear in Table 1 (male) and Table 2 (female) in the columns marked "whole" and were calculated using the following equations:

$$S/V\ \left(\frac{cm^2}{cm^3}\right) = \frac{\Sigma P_i\ (mm)}{\Sigma A_i\ (mm^2)} \cdot 10\ \frac{mm}{cm} \cdot \frac{4}{\pi} \qquad (1)$$

$$\text{Fractional Bone Volume (\%)} = \frac{100 \cdot \Sigma A_i\ (mm^2)}{7.92 \times 10^{-5}\ \frac{mm^2}{pp} \cdot \Sigma F_i\ (pp)} \qquad (2)$$

$$MTC\ (\mu m) = \frac{\Sigma A_i\ (mm^2)}{\Sigma I_i\ (mm)} \cdot 10^3\ \frac{\mu m}{mm} \qquad (3)$$

where P_i, A_i, F_i, and I_i are respectively the bone perimeter, bone area, test frame area, and bone horizontal intercept of the ith frame. The value of $4/\pi$ assumes an isotropic orientation of the trabeculae (1,6).

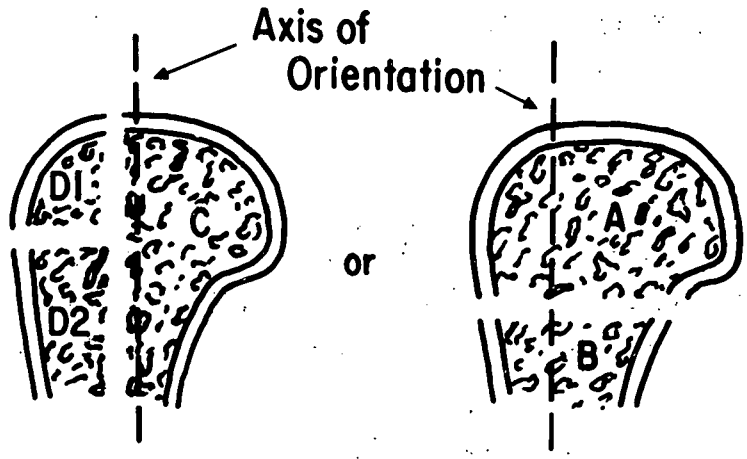


FIGURE 2. Longitudinal section of the proximal humerus.

TABLE 1. MONKEY PROXIMAL HUMERUS (TRABECULAE): MALE

Animal	Age (Years)	$\frac{S}{V}$ $(\frac{cm^2}{cm^3})$			Fractional Bone Volume (Percent)			Mean Trabecular Chord (μm)		
		Whole	Epiph.	Metaph.	Whole	Epiph.	Metaph.	Whole	Epiph.	Metaph.
3282	8.6	216	188	275	18.3	34.0	10.9	175	243	118
3292	9.2	213	196	250	20.1	30.1	14.6	180	219	138
2926	10.0	158	149	162	26.5	36.9	20.4	254	265	259
3293	10.0	212	208	266	20.6	21.5	12.3	177	194	128
2126	11.8	180	150	213	24.0	44.3	18.5	206	315	164
3279	15.8	202	174	254	16.9	34.6	11.1	196	303	138
Mean	10.9	197	178	237	21.1	33.6	14.6	198	256	157
S.D.	2.6	23	24	42	3.6	7.6	4.0	30	47	52
S.E.	1.1	9.4	10	17	1.5	3.1	1.6	12	19	21

TABLE 2. MONKEY PROXIMAL HUMERUS (TRABECULAE): FEMALE

Animal	Age (Years)	$\frac{S}{V}$ ($\frac{cm^2}{cm^3}$)			Fractional Bone Volume (Percent Bone)			Mean Trabecular Chord (μm)		
		Whole	Epiph.	Metaph.	Whole	Epiph.	Metaph.	Whole	Epiph.	Metaph.
2925	6.7	239	223	245	21.10	27.1	19.6	164	200	145
2683	8.6	225	222	259	17.20	21.7	13.2	168	181	135
2492	9.5	152	141	206	27.9	39.1	13.5	277	337	163
3288	11.5	222	170	282	23.4	38.9	13.4	174	226	128
3133	15	228	215	216	14.6	27.3	13.8	172	194	176
3278	15	192	186	234	22.4	32.4	14.5	207	200	149
2374	18	263	193	299	14.9	34.1	9.87	141	210	111
2649	21.5	214	206	247	18.1	28.8	11.4	176	211	123
3287	24.3	160	130	188	23.6	37.4	18.7	236	282	175
3280	25	192	150	218	21.4	45.3	10.9	199	267	156
3291	26	155	150	159	25.6	32.4	17.0	249	244	194
3063	29	209		270	25.2		8.87	182		143
2992	30	178			28.9			213		
3294	31.7	222	172	310	17.9	37.3	9.34	173	242	129
Mean	19.4	204	180	241	21.6	33.5	13.4	195	233	148
S.D.	8.5	33	33	44	4.5	6.6	3.4	38	45	24
S.E.	2.3	9	9	12	1.2	1.9	0.9	10	13	7

The microradiographs were then edited by painting (Kodak Opaque Paint) on the side opposite the emulsion to exclude all of the section except the trabecular region of the epiphysis. An automated scanning program (CORTICAL BONE SCAN, July 25, 1978) was used to determine the trabecular surface-to-volume ratio from the microradiographs of the epiphysis and the metaphysis. (The paint was removed with water and the paint-editing and scanning processes were repeated for the metaphysis. Scanning was performed with a 1X objective and a total optical magnification of 10X.)

The S/V ratio was calculated from the measurements of bone perimeter (P) and bone area (A) using equation (1).

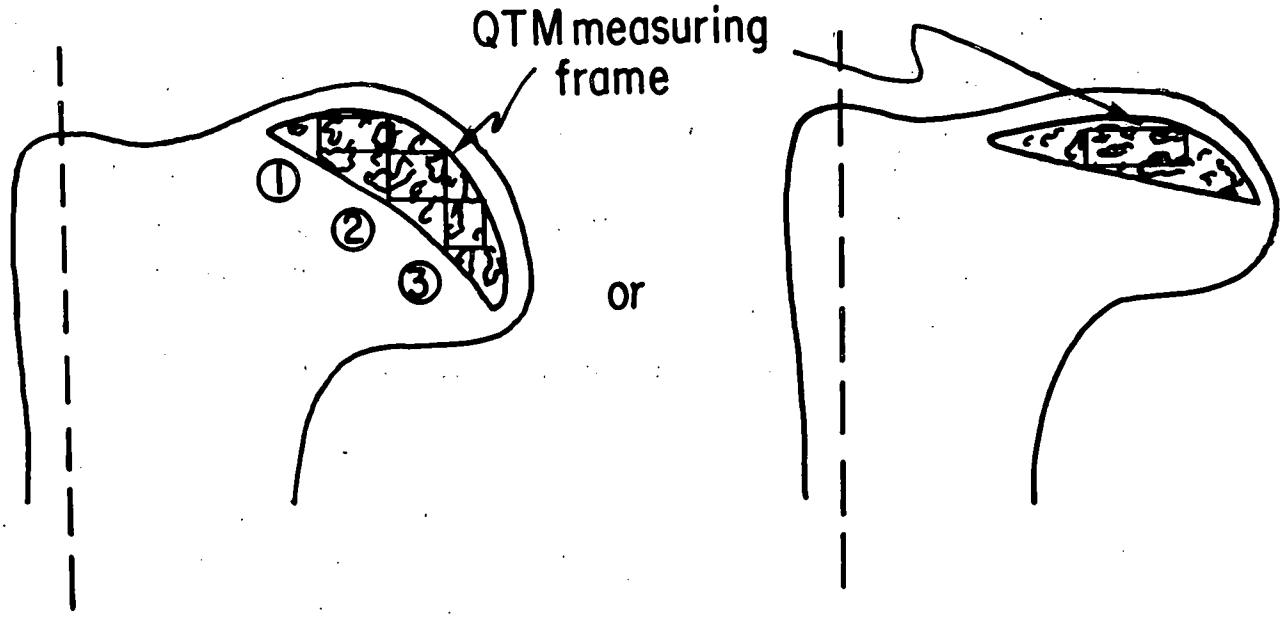
Fractional Bone Volume and Mean Trabecular Chord for the epiphysis and the metaphysis (Tables 1 and 2) were determined by scanning the respective regions with QTM using the program BONE/MARROW PARAMETERS (Nov. 1, 1977) and equations (2) and (3). The orientation was kept constant for measurement of the trabecular chord. The largest practical rectangular measurement frame area was used (in some cases, two or three per section), as shown in Fig. 3.

2. Humeral Cross Section (Cortical Bone)

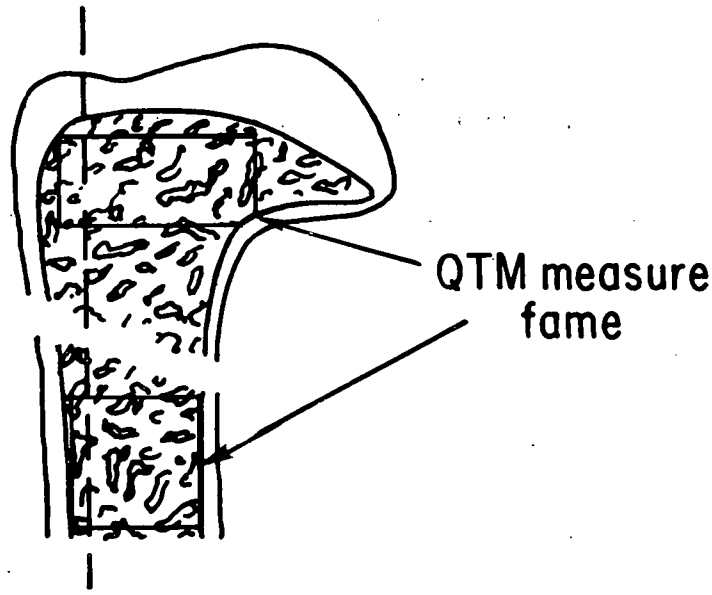
Microradiographs of cross sections of the mid-humeral cortex were prepared and measurements performed on them using the QTM 720 and the automated program, CORTICAL BONE SCAN, (July 25, 1978). No trabecular bone was involved in these measurements. A 4X objective was used and the total optical magnification was 40X. The parameters measured are shown in a sample read-out from the program:

MONKEY 2492 HUMERUS
(CORTEX)

UNITS IN mm
BONE AREA 48.4563
BONE PERIMETER 146.3047
S/V 3.9193
NO. HOLES/AREA[BONE] 18.8004
EST. POROSITY[PC] 3.8587



Measurement areas sampled for epiphysis



Measurement areas sampled for metaphysis

FIGURE 3. Illustration of the epiphyseal and metaphyseal regions of scanning for the proximal humerus.

In this case, the surface-to-volume ratio is given by the ratio of perimeter to area. The number of "holes" per unit area of bone is a parameter related to bone porosity (a "hole" would be an Haversian or Volkmann canal or a resorption cavity). It can be shown that if the porosity of the bone is low (i.e., area of bone is much greater than the area of "holes"), porosity can be estimated by :

$$\text{porosity} \simeq \frac{P^2}{4\pi\, NA}, \qquad (5)$$

where P is the bone section perimeter, N is the number of "holes," and A is the bone area. For low porosity bone equation (5) is probably good to a precision of ± 25% with the present technique.

Table 3 lists the results for the scanning of each cortical cross-section of the humerus.

3. Vertebra (Trabeculae)

Microradiographs of the vertebrae were edited by painting the side opposite the emulsion to eliminate the cortex from the field of view during scanning with the QTM 720. The trabecular surface to volume ratio was obtained using the automated scanning program (CORTICAL BONE SCAN, July 25, 1978) on the Quantimet. A 1X objective was used and the total magnification was 10X.

The surface to volume ratio was obtained by the formula:

$$S/V \left(\frac{cm^2}{cm^3}\right) = \left(\frac{mm}{mm^2}\right) \quad \frac{4}{\pi} \cdot 10 \text{ (Note: } \frac{P}{A} \text{ is } \frac{S}{V} \text{ in the program).}$$

The readings for No. Holes/Area [Bone] and Est. Porosity [PC] derived from this program are invalid parameters when applied to trabecular bone.

The Fractional Bone Volume (percent Bone) and the Mean Trabecular chord were calculated by using the program BONE/MARROW PARAMETERS (Nov. 1, 1977). As a large a rectangular measurement frame area as possible was used, and the axis of orientation was kept constant (Fig. 4). Results are shown in Table 4.

TABLE 3. MONKEY HUMERUS (CORTICAL CROSS SECTIONS)

Animal	Age (Years)	$\frac{S}{V}$ $(\frac{cm^2}{cm^3})$	Porosity (Percent)
Females:			
2925	6.7	28.9	3.98
2683	8.6	28.9	4.12
2492	9.5	30.2	3.86
3288	11.5	35.9	4.86
3133	15	41.3	8.19
3278	15	23.7	2.67
2374	18	36.0	5.25
2649	21.5	37.4	5.73
3287	24.3	36.4	6.00
3280	25	33.4	4.81
3291	26	37.3	5.39
2992	30	34.4	4.86
3294	31.7	44.0	8.13
Mean	18.7	34.4	5.22
S.D.	8.4	5.5	1.57
S.E.	2.3	1.5	0.44
Males:			
3282	8.6	40.8	6.75
3292	9.2	32.0	3.32
2926	10	33.9	4.19
3293	10	25.5	2.91
2126	11.8	27.3	2.75
3279	15.8	32.3	3.72
Mean	10.9	32.0	3.94
S.D.	2.6	5.4	1.47
S.E.	1.1	2.2	0.60

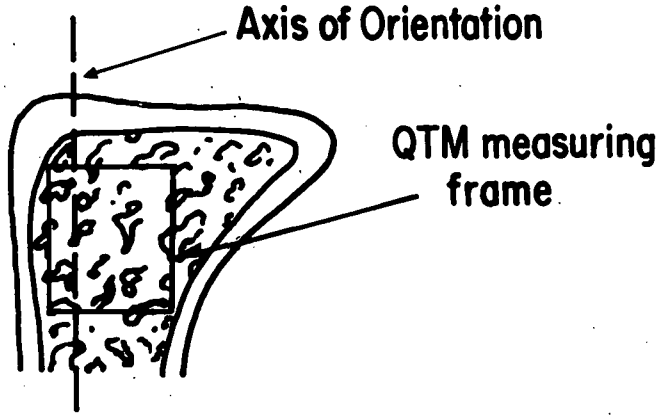


FIGURE 4. Longitudinal section of the vertebra.

TABLE 4. MONKEY VERTEBRA (TRABECULAE)

Animal	Age (Years)	$\frac{S}{V}$ (cm^2) / (cm^3)	Fractional Bone Volume (% Bone)	Mean Trabecular Chord (μm)
Females:				
2925	6.7	261	22.4	134
2492	9.5	287	14.2	108
3133	15	299	16.8	117
3278	15	273	25.0	124
2649	21.5	282	11.6	111
3287	24.3	145	26.9	179
3063	29	207	28.5	149
3294	31.7			
Mean	17.6	251	20.8	132
S.D.	10.6	55	6.6	25
S.E.	3.8	21	2.5	9
Males:				
3282	8.6	251	17.6	126
3292	9.2	263	19.2	137
2976	10	202	27.1	151
3293	10	241	22.6	136
3279	15.8	258	15.6	125
Mean	10.7	243	20.4	135
S.D.	2.9	24	4.5	10
S.E.	1.3	11	2.0	5

4. Calvarium (Trabeculae)

Microradiographs of sections from the calvarium were scanned on the Quantimet 720 with a 1X objective and a total optical magnification of 10X. Only the trabecular portion of the bone was included. This was done using the Image Editor module to circumscribe the trabecular area and exclude the cortex and any blank region of the test frame area. The frame area (in units of picture points) to be measured was recorded, and the manual program (BONE/MARROW PARAMETERS, Nov. 1, 1977) recorded other data to be used in the calculations. Several adjacent frames were needed to measure an entire sample and the orientation was kept constant (Fig. 5).

The following parameters were calculated from the recorded data: Surface to volume ratio, fractional bone volume (percent bone), and mean trabecular chord. These results are shown in Table 5.

Discussion

General observations, which are noted in Tables 1-5 are the following:

1. The fractional bone volume for the trabecular bone of the calvarium is approximately a factor of 2 higher than that of the trabecular bone of the proximal humerus or the vertebra.
2. As we would expect, the Surface/volume ratio of the cortical bone within the humeral shaft is much lower than that of the trabecular bone within the other skeletal sites.
3. In the trabecular region of the proximal humerus the Surface/volume ratio is greater in the metaphysis than in the epiphysis. This is due to the thicker trabeculae within the epiphysis, as can be seen from the mean trabecular chord measurements. The fractional bone volume is also significantly greater in the epiphysis.

The means ± SD of three parameters (surface/volume, percent bone volume or porosity, trabecular chord) in five bone sites in young adult male and female rhesus monkeys are shown in Table 6, and in older females, in Table 7. Only two statistically significant differences were found between the parameters of the males and females of comparable age. The mean trabecular chord

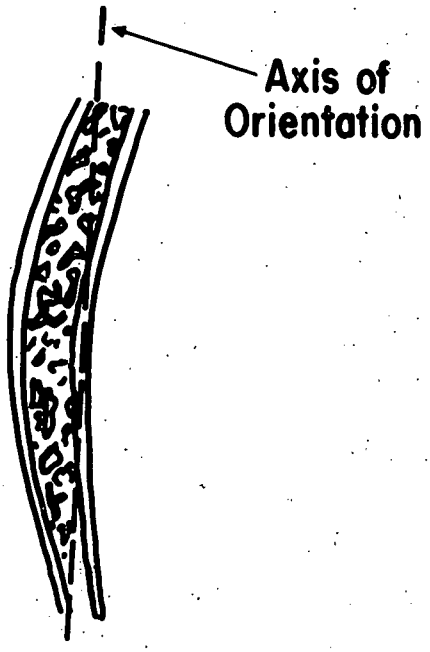


FIGURE 5. Longitudinal section of calvarium.

TABLE 5. MONKEY CALVARIUM (TRABECULAE)

Animal	Age (Years)	$\frac{S}{V}$ (cm^2) / (cm^3)	Fractional Bone Volume (% Bone)	Mean Trabecular Chord (μm)
Females:				
2925	6.7	168	55.6	205
2683	8.6	195	44.8	174
3133	15	182	41.5	198
2374	18	143	72.7	264
2649	21.5	137	53.8	247
3287	24.3	143	44.0	254
3291	26	113	71.1	302
3063	29	134	70.6	265
Mean	18.6	152	56.8	239
S.D.	8.1	27	13.1	42
S.E.	2.9	10	4.6	15
Males:				
3292	9.2	187	51.4	189
2926	10	165	63.9	212
3293	10	168	54.8	209
2126	11.8	140	48.2	256
Mean	10.2	165	54.6	216
S.D.	1.1	19	6.8	28
S.E.	0.6	10	3.4	14

TABLE 6. PARAMETERS OF TRABECULAR BONE OF ADULT MALE AND FEMALE RHESUS MONKEYS 6.7 TO 15.8 YEARS OF AGE

	Female			Male		
	No.	Mean	SD	No.	Mean	SD
Humerus						
Proximal end (trabeculae)						
S/V(cm^2/cm^3), epiphysis	6	193	33	6	178	24
metaphysis	6	240	28	6	237	42
entire prox. end	6	210	32	6	197	23
Percent bone, epiphysis	6	31.1	7.0	6	33.6	7.6
metaphysis	6	14.7	2.4	6	14.6	4.0
entire prox. end	6	21.1	4.7	6	21.1	3.6
Trabecular chord (μm), epiphysis	6	223	58	6	256	47
metaphysis	6	149	18	6	158	52
entire prox. end	6	194	44	6	198	30
Cross-section of diaphysis						
S/V(cm^2/cm^3)	6	31.5	6.2	6	32.0	5.5
porosity (%)	6	4.61	1.89	6	3.94	1.47
Lumbar Vertebral Body (trabeculae)						
S/V (cm^2/cm^3)	6	292[a]	28	5	243[a]	24
Percent bone	6	19.4	4.	5	20.4	4.5
Trabecular chord (μm)	6	119[b]	10	5	135[b]	10.
Calvarium (trabeculae)						
S/V (cm^2/cm^3)	3	182	13	4	165	19
Percent bone	3	47.3	7.4	4	54.6	6.6
Trabecular chord (μm)	3	192	16	4	216	28

[a] $P \sim 0.01$

[b] $P < 0.01$

TABLE 7. PARAMETERS OF TRABECULAR BONE OF AGING (18 TO 31.7 YEARS OLD) FEMALE RHESUS MONKEYS

	No.	Mean	S.D.	P[b]	Age Trend[a]
Humerus					
Proximal end (trabeculae)					
S/V (cm^2/cm^3), epiphysis	6	167	29		
metaphysis	7	242	56		
entire prox. end	8	199	36		
Percent bone, epiphysis	6	35.9	5.6		+
metaphysis	7	12.3	3.9		-
entire prox. end	8	22	4.7		
Trabecular chord (μm), epiphysis	6	243	29		
metaphysis	7	147	30		
entire prox. end	8	196	36		
Cross-section of Diaphysis					
S/V (cm^2/cm^3)	7	37.0	3.4	~0.1	+
Porosity (%)	7	5.74	1.14	~0.05	+
Lumbar Vertebral Body (trabeculae)					
S/V (cm^2/cm^3)	7	244	70		-
Percent bone	7	22.7	6.8		+
Trabecular chord (μm)	7	146	34	0.1	+
Calvarium (trabeculae)					
S/V (cm^2/cm^3)	5	134	12	<0.01	-
Percent bone	5	62.4	13	0.1	+
Trabecular chord (μm)	5	266	21	<0.01	+

[a]Age trend (+) to greater values; (-) to lower values; ( ) no age trend.

[b]P Statistic based on t-test of Fisher; where no value is shown P > 0.10 and differences are not considered significant.

in the lumbar vertebrae of the males was larger (and the surface/volume, smaller) than of the females. In the bones of both sexes the fractional bone volumes were the same, suggesting a larger number of trabeculae in the vertebrae of the females.

In the aging females, although there was a tendency towards more trabecular bone (percent bone) in the humeral epiphysis with age, the trend is not significant. There was also a suggestion of less trabecular bone with age in the metaphysis. There were no age-related changes in trabecular dimensions in the humerus. In the humeral diaphysis the trend with advancing age was towards greater porosity.

In the lumbar vertebrae, and even more markedly in the calvarium, there was an age-related trend towards coarser trabeculae, smaller values of surface/volume, and larger fractional bone volumes. The trend in the calvarium was highly significant, and filling of marrow spaces by bone was apparent from visual inspection of the sections.

Arnold and Wei (2) measured the dimensions and amounts of trabecular bone in thick sections of lumbar vertebrae of 35 aging human males and females (presumably all Caucasians). The age trends in both sexes were towards fewer numbers of smaller trabeculae and less bone per volume of skeletal tissue.

Thus, the changes with age in vertebral trabeculae of caged female rhesus monkeys appear to be in the opposite direction to those found in Arnold and Wei's sample of human skeletons. There is evidence suggesting that not all aging human skeletons undergo osteoporotic changes of the same magnitude or on the same time schedule. Gross dry and ash weights of skeletons and individual bones reported by Broman, *et al.* (7), for a series of 80 male and female skeletons of American Whites and Blacks, indicate that osteoporosis in the lumbar vertebrae is either uncommon or absent in Black males. The observation of an aging pattern in non-human primates that does not mimic a particular human sub-population and should not preclude by itself the use of non-human primates in research on bone and bone-seeking radionuclides.

The data in the present study may be compared with results of other studies. The following are means ± SD for from six to 20 values, each obtained from measurements of trabecular bone in several sections of different bones from the same individual (4), or of single sections from several bones or of the same bone taken from several individuals (10; this report):

		Man	Dog	Monkey
Beddoe:	S/V (cm^{-1})	187 ±24	200 ±55	204 ±51
	Percent Bone	16.0± 3.5	34.2±11.5	26.1± 8.2
	Mean Trabecular Pathlength (μm)	253 ±18	216 ±40	227 ±64
Srisukonth, *et al.*:	S/V (cm^{-1})	---	204 ±36	---
	Percent Bone	---	40.6± 8.9	---
	Mean Trabecular Width (μm)	---	133 ±26	---
Present Study:	S/V (cm^{-1})	---	---	216 ±44
	Percent Bone	---	---	32.6± 6.3
	Mean Trabecular Chord (μm)	---	---	181 ±48

The differences in mean trabecular size reflect different definitions and measurement techniques for that parameter. The means and the ranges of the parameters for the two laboratory animals were not different from each other or from the values reported for the adult male human skeleton, with the exception that fractional bone volume may be lower in man. For those radiation dosimetric quantities that are dependent on structural dimensions -- trabecular sizes, bone surface/volume, % fractional bone volume -- both the beagle dog and the rhesus monkey are good models for man.

From Beddoe's data it is clear that the assumption for dosimetric purposes of a trabecular thickness of 100 μm (9) is in error. Because of the fundamental relationship between trabecular chord and bone surface/volume, the assumption of such a small value for trabecular thickness leads to unduly high calculated value of trabecular surface/volume.

Acknowledgments

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A SIMULATION OF ^{239}Pu LOCATION IN TRABECULAR BONE: A COMPUTERIZED MODEL OF ADULT ENDOSTEAL BONE REMODELING AND ITS INTERACTION WITH INJECTED ^{239}Pu

D. B. Kimmel and W. S. S. Jee

ABSTRACT: A computer simulation of the relationship of bone microanatomic metabolic activity to the microscopic location of ^{239}Pu in bone has been attempted. The model incorporates the rate of bone turnover, cell location and density, bone resorptive activity (as it removes ^{239}Pu from bone), bone formation activity (as it buries ^{239}Pu in bone), recycling of ^{239}Pu, and liver translocation of ^{239}Pu to bone, such that the skeletal retention curve for ^{239}Pu injected in monomeric form into the young adult beagle is matched. The eventual aim of this work is to calculate the radiation dose to bone cells, knowing the relative location of ^{239}Pu deposited in bone and the cells that reside at bone surfaces as it changes throughout the lifespan of an animal. Early results indicate that osteosarcoma incidence may be proportional to the number of alpha hits which occur to osteoprogenitor cells and osteoblasts, the dividing cell population found near surfaces where bone turnover is in progress.

INTRODUCTION

It is well established that alpha-emitting, skeletally-deposited radionuclides cause bone cancer. The mechanism by which they act is not well understood. One aspect of the mechanism is knowing the radiation dose to bone cells which is associated with the induction of osteosarcoma. If this is known, basic principles of cellular radiation biology learned from studies of simple systems, concerning cell killing, repair, and transformation, may be applied. Calculating this cellular radiation dose is a complex problem since the relation of the deposited radionuclide to the cells must be known. Most evidence indicates that: 1) this relationship is changing constantly due to metabolic activity which is continually changing the structure of the hard tissue bone in which the nuclide is sequestered ("modeling" during growth and "remodeling" during adulthood), 2) the relationship is

different in different areas of bone, and 3) the localized concentrations of bone-seeking radionuclides are highly variable.

Pu-239 is straightforward because it is a "surface seeker" and gives rise mainly to tumors of the endosteal bone surface, so studies can be confined to that type of surface. It is further desirable to limit studies to the young adult beagle, 1) so studies of adult bone, similar to that of humans, are possible, and 2) data on osteosarcoma induction as a function of injected dose of ^{239}Pu now available may be utilized.

One way to study the microanatomic relationship of ^{239}Pu to bone cells and bone mineral is by autoradiography of bone taken from several beagles injected with ^{239}Pu and sacrificed serially after ^{239}Pu injection. These studies have shown that: 1) ^{239}Pu is initially deposited non-uniformly on endosteal bone surfaces, when injected as a citrate solution; 2) it is removed in areas of bone resorption activity; 3) it is buried in areas of bone formation activity; and 4) it is recirculated to existing surfaces.

These studies have provided an excellent qualitative start to describing the microanatomic location of ^{239}Pu relative to cells. Even when adequate quantitative autoradiographic methods are available, there is great difficulty in expressing the data in a meaningful manner, because any collected data is almost inevitably averaged in concentrations over regions of surface quite a bit larger than both the size of bone cell nuclei and the range of the ^{239}Pu alpha particle. This results in loss of potential meaning from the data. In addition, problems such as site-specific depth-of-burial, localized variation in surface concentration, the relative location of bone cells, radiation toxicity to the bone remodeling process, the multiplicity of sites which must be studied, and interanimal variation, present grave obstacles.

Another totally different approach to the problem is to construct a model which 1) incorporates what is known about the systematic nature of the organization of bone remodeling activity, 2) adheres judiciously to the qualitative rules concerning ^{239}Pu in bone, and 3) matches various bits of quantitative data on ^{239}Pu retention in the skeleton.

BACKGROUND DATA

A. The Organization and Metabolic Activity of Adult Endosteal Bone

The evidence for this organization is discussed in full elsehwere (3). Briefly, adult endosteal bone is organized into discrete packages; each is called a remodeling unit and has as its sole purpose, being renewed periodically with new bone, to maintain skeletal structural integrity. From time to time, in a process under some form of hormonal and mechanical control, the contents of each unit are fully removed, then fully replaced. It is generally assumed that older units have a greater chance of being acted upon. Osteoclasts resorb the bone; osteoblasts form the new bone; and only resting endosteal lining cells are present at the surface of each filled unit.

B. Assumptions for ^{239}Pu Metabolism in Bone

These are as follows: a) ^{239}Pu introduced in monomeric form to the bloodstream is deposited randomly at bone surfaces, b) ^{239}Pu found at resorbing surfaces and in resorbed volumes of bone is removed and given to the blood, c) ^{239}Pu found at forming surfaces is buried beneath the bone surface, and d) no physicochemical translocation of ^{239}Pu from or within bone takes place.

C. Quantitative Data Available

1) The fraction of injected ^{239}Pu retained in the skeleton at levels considered to have minimal effect on bone remodeling in the young adult beagle is described by the equation:

$$0.286e^{-0.0011t} + 0.21$$

where t is the time in days after injection.

2) The initial endosteal surface concentration for ^{239}Pu varies from 8 pCi/cm^2 in endosteal sites of higher bone turnover (proximal humerus, ilium, lumbar vertebral body) to 1 pCi/cm^2 in sites of lower bone turnover (distal humerus, proximal ulna), after injection of 16 nCi/kg into young adult beagles.

3) Of ^{239}Pu in the blood, 78% is recirculated for redeposition in organs and 22% is excreted in feces and urine.

4) The remodeling rate of endosteal bone varies from 30%/yr (distal humerus and proximal ulna) to 200%/yr (proximal humerus, ilium, and lumbar vertebral body).

5) The cell density (lining cells) at resting surfaces is 80 cells/mm^2, while that at forming surfaces (osteoblasts and osteoprogenitor cells) is 5600 cells/mm^2. Surfaces identified as resting always have lining cells associated with them; surfaces identified as forming always have osteoblasts and osteoprogenitor cells associated with them.

6) The fraction of injected ^{239}Pu retained in the liver of the young adult beagle is described by a single exponential equation:

$$0.347e^{-0.000184t}$$

where t is the time post-injection. This rate reflects only a net loss not a two-way flux.

7) The chance of a ^{239}Pu alpha escaping bone is directly proportional to the fraction of a sphere of radius r (the ^{239}Pu alpha range) with center at some depth d in bone, which is located outside the bone volume. Measurements have shown that lining cell nuclei are directly adjacent to the surface and that their nuclear material covers about 1% of the surface at any given resting site. It is assumed that 1% of all alpha particles which escape from the bone volume at resting sites strike lining cell nuclei. Measurements have also shown that osteoprogenitor cell nuclei are about five microns from the bone surface and that the fraction of surface covered by their nuclear cytoplasm at this distance is 1. It is assumed that all alpha particles which escape to a distance of five microns from the bone volume at forming sites strike osteoprogenitor or osteoblast nuclei.

8) The lifespan of lining cells or osteoblasts and osteoprogenitor cells is not well known. For this preliminary work, it is assumed that their lifespan is equal to that of the young adult beagle, or 12.5 years.

PROCEDURE IN PROGRAMMING

A) The Bone - The age of each remodeling unit is recorded in a one-dimensional array (A). This age changes individually as units experience cycles of remodeling activity and resting phases.

The ^{239}Pu content of each remodeling unit is recorded in a two dimensional array (B) as a function of distance from the endosteal surface and

concentration for each individual unit. The second dimension, distance from the surface, is divided to represent about one micron per unit step in the array (See Figure 1).

B) The Remodeling of Bone and the Mobilization of ^{239}Pu - The resorption operator (R) is directed by a random process to find a relatively old unit of bone and to resorb all bone (and ^{239}Pu) found in it. The ^{239}Pu is liberated to the blood where 78% is redeposited randomly to endosteal surfaces and the remaining 22% is excreted. The formation operator (F) is directed to follow immediately the R operator at each site and deposit a small amount of bone in the unit, burying whatever ^{239}Pu might have been at the surface. The F operator continues to work in each area until the bone mass is back to the original. New units are activated in staggered sequence and continue out of phase. The rate of remodeling is adjustable, so that a given fraction of the bone is renewed yearly; for instance, if 100% turnover/yr was desired, a number of units equal to the total number in the bone would be remodeled each year.

C) The Calculation of Dose - Whenever the location of ^{239}Pu has been completely systematically reevaluated as it would be changed by the bone remodeling system (once per 2-3 days), the average number of hits to osteoblasts and osteoprogenitor cells (at forming surfaces) and bone lining cells (at resorbing surfaces) is calculated by knowing ^{239}Pu quantity and location relative to the surface of each individual unit. As it is currently done, the dose to cells is pursued in a very unsophisticated manner as: 1) no attempt to calculate path length through nuclei is made, 2) no attempt to calculate energy deposition is made, 3) no attempt to differentiate alphas stopping in the nucleus from alphas passing through the nucleus is made, and 4) no attempt to calculate cytoplasmic dosage of any sort is made. The more important contribution of this model is in giving a systematic way to locate ^{239}Pu in bone.

DOSE RESULTS IN ONE SITUATION

The total number of disintegrations striking members of each cell population is described in Table 1 in a young adult beagle injected with 0.7 nCi/kg, the least amount of injected ^{239}Pu to ever cause osteosarcoma in this

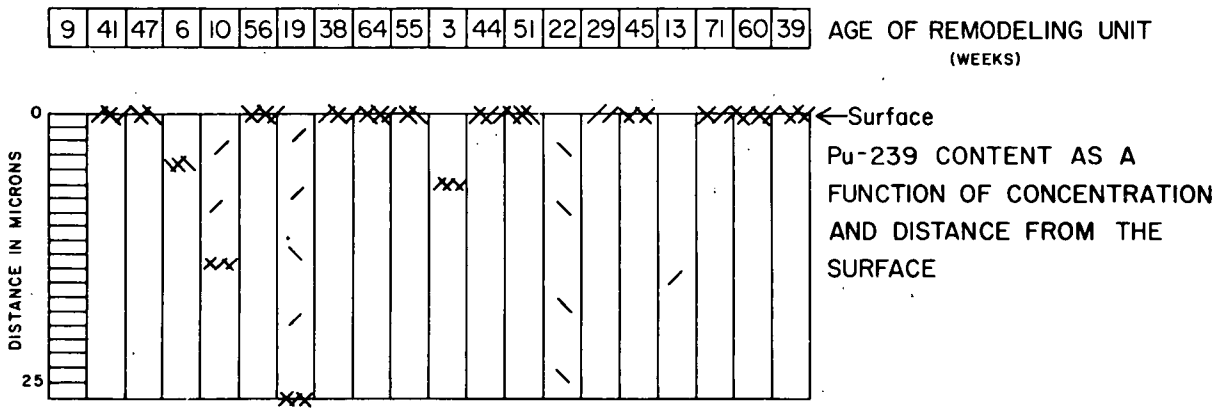

FIGURE 1 BONE AGE AND ^{239}Pu CONTENT REPRESENTATION IN COMPUTER

The age of individual remodeling units is used to direct the location of new remodeling activity. If the unit of age "64", one of the older ones, were selected for remodeling, the corresponding unit in the ^{239}Pu content array would be evacuated of bone and ^{239}Pu and the age reduced to "0"; at the same time all other units would age "1" unit. The remodeling unit would then age as it refills and passes to a resting phase, aging further as it awaits a new remodeling cycle.

colony. The lifespan of beagles at this level is 12.5 years.

For endosteal sites of high turnover, the number of hits to the nuclei of the resting population in an area of 150 cm^2 is 4.5×10^5, but that to the forming cell population is 2.6×10^5 during the first 18 days after injection and 3.5×10^6 for the remaining lifespan. For endosteal sites of low turnover, the number of hits to the resting population in a 150 cm^2 area is 1.9×10^5, but that to the forming population is only 8.4×10^4 during the first 18 days after injection and 3.0×10^4 for the remaining lifespan.

Consider a simple situation, that tumor incidence is directly proportional to total lifetime radiation dose to some cell population whose lifespan is equal to that of the organism. If irradiation of the lining cell population produced osteosarcoma, then one would predict that osteosarcoma incidence in the high turnover sites in the beagles would be only about twice that in the low turnover sites. If irradiation of the forming cell population produced osteosarcoma, then one would predict that osteosarcoma incidence would be 30X, if only the first 18 days were important, or 118X, if the lifespan dose were critical, that found in the low turnover sites. In fact, as the data on actual osteosarcoma appearance are listed in Table 2, the ratio of osteosarcoma incidence in high and low turnover sites could easily be thirty or more.

DISCUSSION

The main purpose for constructing computer models of dynamic biological systems is to find whether the understanding of the way in which the systems function is correct. They are constructed from available data and used to make some predictions. Experiments are then conducted to produce actual results under the conditions imposed by the model.

This method of finding the location of ^{239}Pu in bone and calculating dose, predicts that the forming cell population of an endosteal site may be the most critical one at risk in induction of an osteosarcoma. For comparison, the model of Marshall and Groer (2) suggests that two hits to resting bone surface cells plus the promotion caused by the activation of a remodeling site are the critical events in osteosarcoma onset. Both models are based upon some sort of cumulative lifespan dose to bone or cells.

TABLE 1

HITS ACCUMULATED IN HIGH AND LOW TURNOVER SITES IN BEAGLES LIVING 12.5 YEARS AFTER INJECTION OF 0.7 nCi/kg ^{239}Pu

Cell Population *	High Turnover Site (210%/y)	Low Turnover Site (28%/y)	Ratio of High to Low
Endosteal Lining Cells (during 12.5 Years)	4.5×10^5	1.9×10^5	2.4
Osteoblasts and Osteoprogenitor Cells (first 18 days only)	2.55×10^5	8.4×10^3	30
Osteoblast and Osteoprogenitor Cells (remainder of lifespan)	3.5×10^6	3.0×10^4	118

* Cell population per 150 cm^2 and time period

TABLE 2

RELATIONSHIP OF OSTEOSARCOMA INCIDENCE, BONE TURNOVER, AND INITIAL ^{239}Pu UPTAKE AT VARIOUS SITES OF ENDOSTEAL SURFACE

Site	Fraction of Osteosarcomas*	Turnover Rate (%/y)	Initial ^{239}Pu Concentration**
Lumbar Vertebral Body	0.13	230	8
Pelvis	0.12	200	8
Proximal Humerus	0.12	210	8
Proximal Ulna	0.01	25	1
Distal Humerus	0	30	1

* Fraction of all osteosarcomas in ^{239}Pu-injected beagles which occurred at this site

** Initial ^{239}Pu concentration (pCi/cm^2) after injection of 16 nCi/kg.

The Marshall-Groer model engenders long periods of time between induction, the accumulation of damage in a nucleus of two hits, and promotion, the activation of damaged cells to divide. But repair of DNA damage in non-dividing cells is of the excision repair type, which is relatively accurate, if variable in rate. Repair of damage to DNA in dividing cells tends to be error-prone in bacteria (1). If this is also true in mammalian cells, cells like osteoprogenitor cells have a high probability of retaining damage to their DNA which could lead to the induction of a tumor. More recent evidence suggests that acute damage to enzymes involved in replication of DNA may be a critical factor in carcinogenesis (1). The chance of a ^{239}Pu alpha particle striking osteoprogenitor cells or osteoblasts, which are more numerous in high turnover sites, which are about to divide, coupled with the invoking of error-prone mechanisms of repair and faulty enzymes of replication, may be a critical event which initiates osteosarcoma. The process is clearly very complicated, though, because it is well-known that one acute incident of irradiation may cause osteosarcoma with a latent period of several years.

The validity of the current model remains to be shown. It has produced no data with which to compare the actual location of ^{239}Pu as seen on autoradiographs of endosteal bone from beagles injected and then serially sacrificed. It assumes that the lifespan of the various populations is equal to that of the whole animal. It assumes that the osteoprogenitor-osteoblast group of cells is unrelated to the resting cell population, when nothing is known in this area. Furthermore, its dosimetric assumptions are very crude. Future work is planned to overcome these difficulties.

Prediction of effects is one of many potential uses for this type of model. It is planned in the future to try different administration patterns of ^{239}Pu. One obvious one is the deposition of ^{239}Pu in bone from an inhaled burden residing in the lung but dissolving slowly. Studies of bone histomorphometry of human and beagle bone are gradually yielding more accurate information on turnover rates, which will be incorporated into the model at a future date. It is also planned to study other surface-seeking nuclides, such as ^{241}Am and ^{228}Th, whose decay properties are different from that of

^{239}Pu. It is also planned to complete work with ^{226}Ra and ^{224}Ra, so that the best available human data on osteosarcoma induction by alpha emitters can also be studied with this approach. Above all, it is planned to pursue more elegant studies of cell density, location, and proliferative capacity, in attempts to calculate the chance of a particle striking a cell about to divide.

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THE EARLY DISTRIBUTION OF Pu IN JUVENILE BEAGLES

F. W. Bruenger, D. R. Atherton, J. M. Smith, R. R. Greenlee, D. S. Buster and W. Stevens

ABSTRACT: Four juvenile beagles, 90 days of age, were given an intravenous injection of 2.5 μCi ^{239}Pu/kg and sacrificed in pairs 7 days and 14 days post-injection (P.I.). At autopsy, the liver contained 15.9% of the injected dose at 7 days and 10% at 14 days P.I. The Pu distribution in the liver was diffuse. About 40% of the deposit was bound to ferritin or associated with microsomes and approximately 50% was found in fractions of high acidhydrolase- and/or cytochrome-c-oxidase activity. Other soft tissue organs retained only very small fractions of the injected dose.

The skeletal retention of 64.3% was not statistically different from the retention of 69.9% calculated for juvenile beagles injected with 0.1 μCi Pu/kg. This confirms that the initial deposition is dependent on the age at injection but is independent of the dose level. The relative concentration of Pu among the various skeletal parts and within individual bones was more uniform in juvenile beagles than in those injected as young adults. The highest concentrations were found in primary spongiosa where the surface/volume ratio was large and where the rate of bone formation was very high. Retention and distribution were related to overall- and localized skeletal growth patterns.

INTRODUCTION

The biological effects of ^{239}Pu in 90 day old beagles (juveniles) have been described earlier (1). In that experiment, 12 juvenile beagles received an intravenous injection of 2.8 μCi ^{239}Pu/kg in citrate buffer. Animals were allowed to live until they succumbed to osteosarcoma by 1306 ± 163 days post injection (P.I.). At time of autopsy, the distribution and retention of Pu in the skeleton and soft tissue organs was studied. No data were available to extrapolate the initial deposition from terminal retentions. Therefore the calculation of radiation dose had to be based solely on the measured retention of Pu in juveniles injected with the much lower dose of 0.1 μCi Pu/kg and sacrificed serially making the assumption that the initial deposition was independent of dose level. In order to verify this assumption and also to compare the initial microdistribution of the nuclide with that observed at approximately 1300 days P.I., the following short-term experiment was conducted.

METHODS

Four 90 day old beagles were injected with an average of 2,5 µCi ^{239}Pu/kg and sacrificed in pairs 7 and 14 days P.I., respectively. Liver, kidney, spleen, some other selected soft tissue organs and the skeleton were collected at autopsy, freed from the surrounding tissue and subjected to routine radiochemical analysis. A subcellular separation of a liver homogenate was done by zonal centrifugation (2). Selected specimens of special interest were prepared for neutron-induced auto-radiography (NIAR).

RESULTS AND DISCUSSION

Of all soft tissue organs, only the liver contained a substantial concentration of Pu. At 7 days P.I., the average retention in the liver was 15.9% and at 14 days it was 10.0% of the injected dose. This does not imply that Pu is lost rapidly from the liver of juvenile beagles since an average respective retention of [12.7 ± 2.0]% was observed in the corresponding long-term study (1). The nuclide was distributed diffusely throughout the liver as shown by the neutron-induced autoradiograph in Fig. 1. Zonal centrifugation showed that of the total Pu in the homogenate at 7 and 14 days approximately 40% was present as Pu-ferritin or associated with a fraction which was high in glucose-6-phosphatase activity (microsomes) and approximately 50% was present in organelle fractions which exhibited acidhydrolase- and cytochrome-c-oxidase activity.

The average ash wt/wet wt ratio of the skeleton was 0.2399. In 7 young adults it was 0.3767. The measured skeletal retention was 57.4% at 7 days and 64.3% at 14 days P.I. This increase is consistent with earlier observations in neonatal beagles (3). It appears that during the early time after injection some translocation of Pu from an initially ubiquitous, low level distribution throughout the soft tissues to a skeletal deposition occurs, although this has not been quantitated in detail. The skeletal retention of 64.3% at 14 days P.I. was slightly lower but not statistically different from a value obtained by extrapolating the measured skeletal retention of a series of beagles injected with only 0.1 µCi Pu/kg to 14 days P.I. Thus it appears that the assumption that initial skeletal deposition of Pu is not influenced by dose level, is confirmed.

TABLE 1

EARLY RELATIVE CONCENTRATION OF Pu IN THE SKELETON OF JUVENILE AND YOUNG ADULT BEAGLES

Skeletal Part	4 Juveniles (7 - 14 Days) R.C. ± σ		5 Young Adults (2 - 40 Days) R.C. ± σ	
Skull	0.520	.050	0.348	.078
Mandible	0.539	.057	0.250	.049
Cerv. V.	0.989	.072	0.864	.197
Thor. V.	1.094	.070	2.319	.244
Lumb. V.	1.142	.062	2.047	.209
Sacrum	1.448	.316	2.133	.665
Caudal V.	1.276	.056	0.412	.274
Paws	1.197	.071	0.210	.049
Radii	1.258	.074	0.264	.102
Ulnae	1.076	.058	0.233	.092
Humeri	1.327	.138	1.509	.194
Scapulae	1.174	.038	1.431	.166
Tib.-Fib.	1.246	.105	0.504	.234
Femora	1.224	.061	1.232	.191
Pelvis	1.136	.024	1.690	.162
Ribs	1.098	.158	1.267	.239
Sternum	0.516	.049	1.700	.449
High R.C./ Low R.C.	1.45/0.52 = 2.8		2.32/0.21 = 11	

* R.C. = Relative Concentration

The distribution of the nuclide among the parts of the skeleton was more uniform than observed in beagles injected as young adults (18 months of age). This is reflected in the values of the relative concentration (R.C.) (fractional skeletal retention/fractional wet skeletal mass) of individual skeletal parts. In Table 1, the R.C. measured in various skeletal parts of beagles injected as juveniles is compared to that found in 5 animals injected as young adults. The relatively small spread of this value in juveniles (1.45/0.52) is the result of the active overall skeletal growth whereas the larger range of R.C. values in beagles injected as young adults (2.32/0.21) is produced by the differential modeling of bone after the animal has reached skeletal maturity. The difference is particularly striking in the radii, ulnae, tibiae and fibulae which in the juvenile are growing rapidly and demonstrate an "above average" R.C. where in the young adult, these bones characteristically have low turnover rates and a "below average" R.C. A more uniform concentration of Pu (% dose/g) also was observed within individual bones. This is demonstrated in Fig. 2. in which the average concentration of Pu in different sections of the four juvenile humeri is compared to the concentration of corresponding sections obtained from three animals injected as young adults. For individual sectioned humeri, the Pu concentration was highly correlated with the respective ash wt/wet wt ratio (correlation coefficients 0.93 - 0.96).

Neutron induced autoradiography demonstrated that in the juvenile, the deposition of Pu strongly depends on the growth characteristics within a particular segment of bone. In Fig. 3, macrophotographs of NIAR sections of the proximal- (a) and distal- (b) epiphysis and metaphysis tegether with a section from the shaft (c) of a humerus show that by 7 days P.I., all trabecular surfaces were heavily labelled with Pu. The highest concentrations of Pu were seen in primary spongiosa, a structure associated only with growing bone and characterized by a high surface/volume ratio. Thus, considerable differences in the concentration of Pu existed in localized areas although the average concentrations in larger samples or among individual bones did not vary greatly.

A higher magnification of the encircled areas of Fig. 3b (distal humerus) is shown in Fig. 4. The upper picture (A) depicts a surface distribution in the epiphysis with a somewhat heavier deposit adjacent to the cartilage of the growth plate. In Fig. 4B the heavy deposit in the primary spongiosa is seen.

It also appears that the adjacent growth plate cartilage at this time (7 days P.I.) has acquired a low diffuse label of Pu. Because of continuing growth and simultaneous erosion of the initial Pu label at the border between primary and secondary spongiosa, surfaces in that area are not as densely and uniformly labelled as are those in secondary, underlying trabeculae as seen in Fig. 4C.

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DISTRIBUTION OF PU IN THE LIVER OF A JUVENILE BEAGLE AT 14 DAYS P.I.

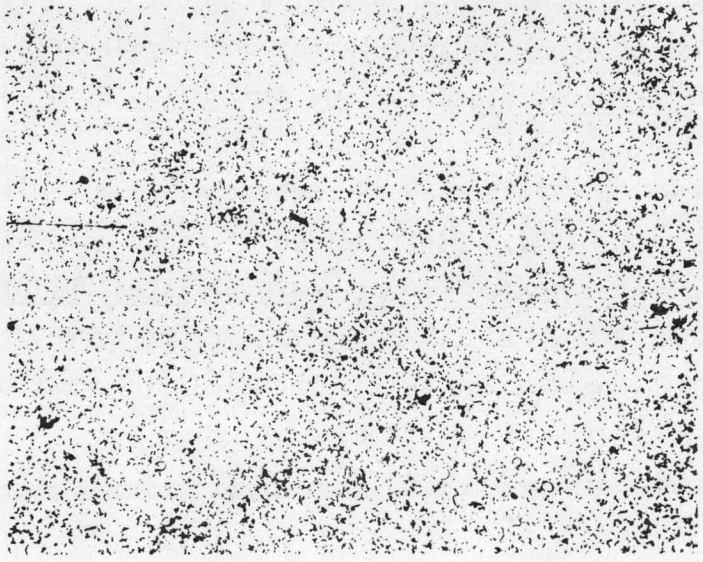

Figure 1. Neutron-induced autoradiograph of plastic-embedded liver section from a juvenile beagle injected with 2.5 μCi Pu/kg and sacrificed 14 days P.I. The early distribution of Pu was uniform and diffuse.

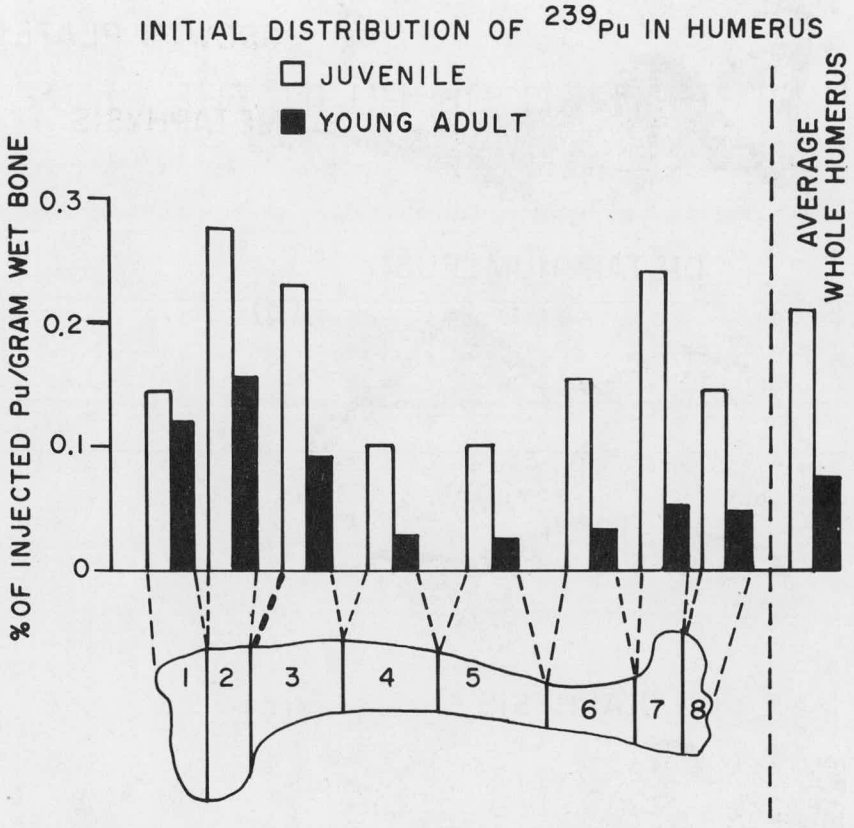

Figure 2. Initial concentration of Pu (% dose/g) in sectioned humeri of 4 juvenile and 3 young adult beagles. The figure shows the overall higher concentration and greater uniformity in the distribution of Pu in the growing bone. Concentrations in individual sections vary by a factor of less than three in the juvenile and by a factor of 6.7 in the young adult.

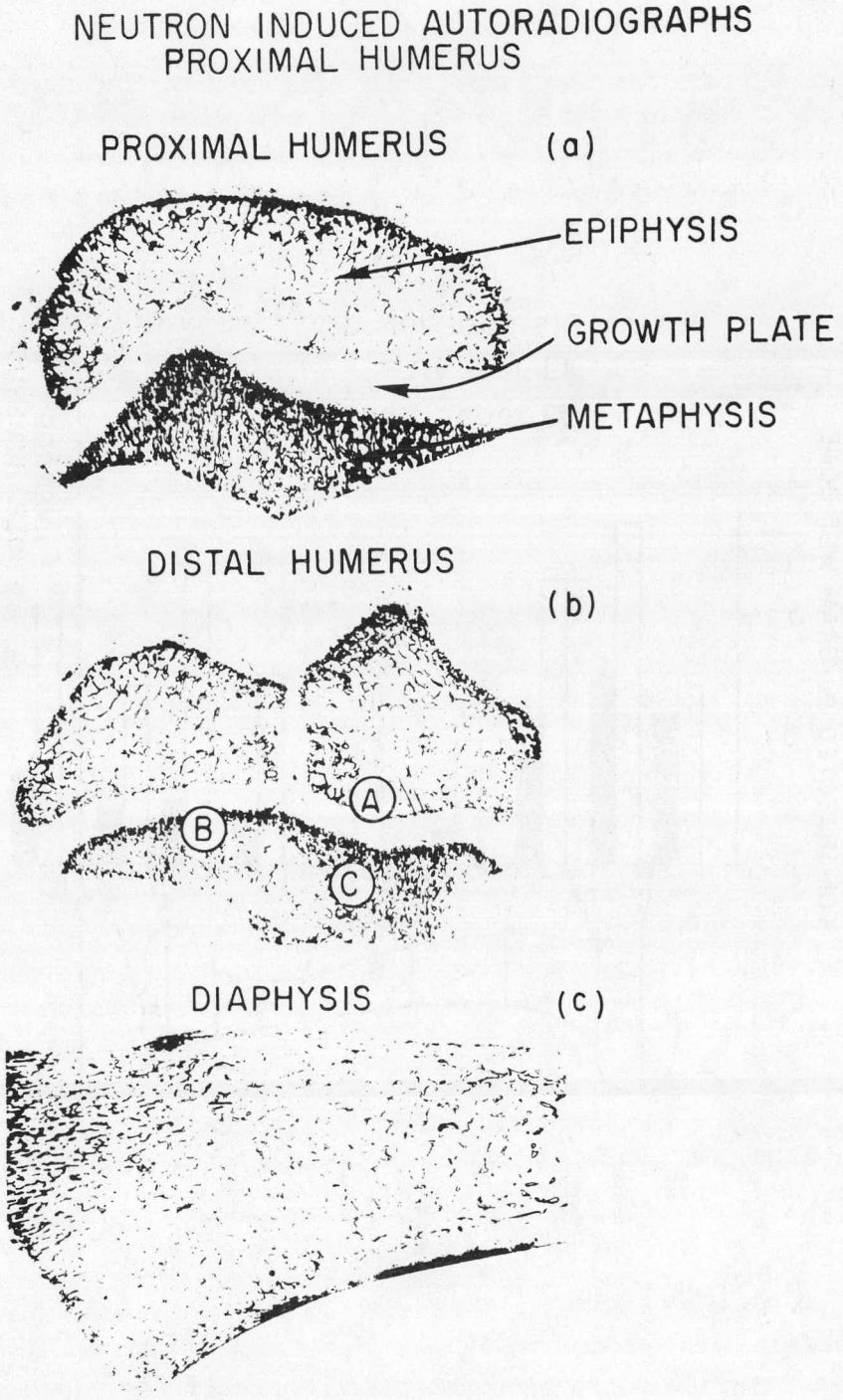

Figure 3. Macrophotograph of NIAR showing the deposition of Pu in the proximal (a), and distal (b) humerus and in the shaft (diaphysis) (c). Encircled areas of the distal humerus were enlarged and are shown in Fig. 4.

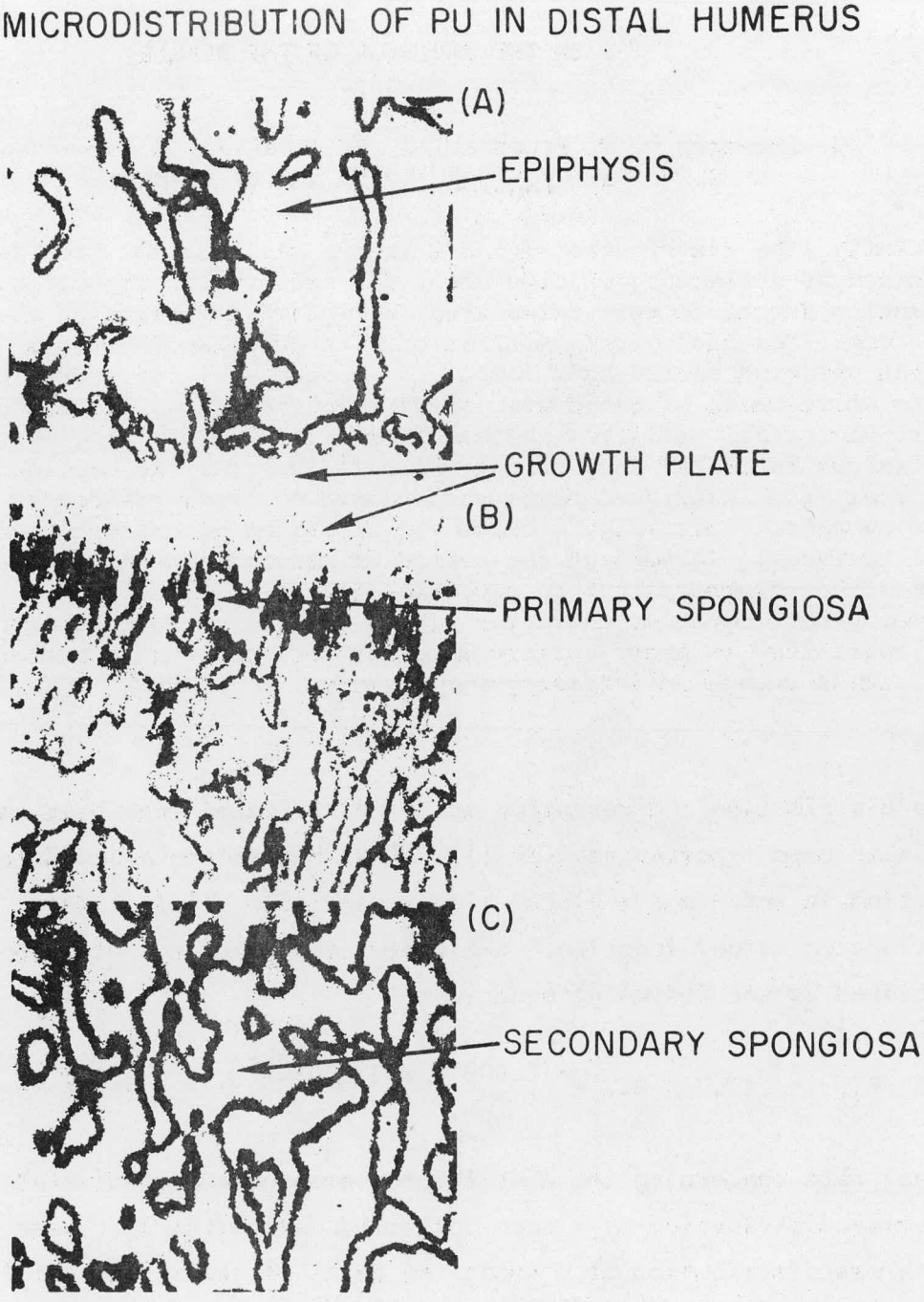

Figure 4. Microphotograph of encircled areas of Fig. 3B. Trabeculae in the epiphysis carry a heavy label of Pu. Only the bone surface adjacent to the underlying cartilage appears to have a higher concentration of Pu. The highest concentration is found in the primary spongiosa (B) while Pu at the borderlines between primary and secondary spongiosa appears to be eroded because of growth. The secondary spongiosa (C) again is heavily and quite uniformly labelled.

^{233}U IN THE SKELETON OF THE BEAGLE

W. Stevens, F. W. Bruenger, D. R. Atherton, G. Howerton,
G. N. Taylor, J. M. Smith and D. S. Buster

ABSTRACT: The distribution of ^{233}U in the skeleton has been determined as a function of time after its intravenous injection. Retention functions were calculated for individual parts of the skeleton. The biological halflife of U in individual members of the skeleton varied by a factor of as much as ∿ 185. Skeletal parts whose ratio of ashed weight/wet weight was low, exhibited short biological halflives whereas those with a high ashed weight/wet weight ratio had long biological halflives for the nuclide. The loss from individual parts was related to their trabecular bone content. Initially, uranium was deposited nonuniformly on bone surfaces. Throughout the period of observation the surface deposition changed partly to a volume distribution but the strongly heterogeneous character of the initial surface deposit was maintained as heavy surface deposits became fewer in number but little change in intensity was observed.

The distribution and retention of ^{233}UVI injected into beagles as the citrate have been reported earlier (1). That report contained data on the distribution in soft- and skeletal tissue, and some clinical data, especially observations on kidney function. Skeletal retention, in % of injected uranium, was described by the following equation:

$$R_{Sk} = (7.7 \pm 0.3)e^{-(0.00078 \pm 0.00012)t} \qquad (t \text{ is in minutes})$$

Additional data concerning the distribution among the various skeletal parts and the microdistribution have been collected during the last year.

The gross distribution of U among the parts of the skeleton followed the general pattern observed with other actinide elements although quantitative differences exist. In general, those skeletal parts which exhibit a high bone turnover rate and which have a high content of trabecular bone (i.e. in which the ratio of ashed wt/wet wt was low (vertebrae, pelvis, humerus) had a higher relative concentration of U, whereas the relative concentration of U was lower in members with a lower turnover rate and/or a high content of cortical bone (i.e. in which the ratio of ashed wt/wet wt was large). Because

of high trabecular bone content with a correspondingly large surface area and because of high turnover rates, the loss of U from these skeletal parts was more rapid than in those with a higher cortical bone content and/or lower turnover rates.

Retention equations were calculated for each individual skeletal part. All bones lost U as a function of time P.I., but in only 8 of the 17 equations was the negative slope statistically different from zero ($p \leq 0.05$). The parameters for each of these equations and the corresponding biological halflives in increasing order together with the respective p values are shown in Table 1. The biological halflives varied by a factor of two orders of magnitude from the highest to the lowest. The differences probably are directly related to vascularity, relative surface area available for exchange and the rate of bone turnover in the individual skeletal parts. Table 1 also demonstrates that bones with a shorter residence time for the nuclide have a considerably lower ashed weight/wet weight ratio, i.e. a higher content of spongiosa than bones whose U content decreased insignificantly with time.

Neutron induced autoradiographs prepared at 1 day, 3 weeks and 364 days P.I. from a bone with a high turnover rate (proximal humerus), one with a very low turnover rate (ulna) and cortical bone from the shaft of a humerus are shown in Figures 1, 2, and 3, respectively.

Initially U is deposited unevenly on endosteal and some periosteal surfaces, the deposit being very heterogeneous and ranging from very intense hot areas to diffuse areas. With increasing time P.I., U is lost unevenly from the surfaces and is either excreted or is found distributed in the volume of the bone. The number of hot spots decrease but the intensity of those remaining appears unchanged. The surface deposits become increasingly heterogeneous, with some very heavy deposits of U still present but the intermediate deposits are lost at times $\gtrsim$ 1 year P.I.. In an NIAR of the proximal humerus (Fig. 1) the initially heavy surface deposits are seen at low magnification. Higher magnification shows that the initial surface deposits are strongly heterogeneous. The diffuse component present at one day is probably caused by residual blood. At 3 weeks and 1 year P.I. the number of intense surface deposits is decreased but those remaining have the same intensity as those observed at earlier times P.I.. Increasing concentrations of U are found in the bone volume

TABLE 1

RETENTION OF URANIUM IN SKELETAL PARTS

	a*	-b	$t_{1/2}$**	p	$\frac{\text{ashed wt}}{\text{wet wt}}$
Sternum	0.2627	0.00269	257	< 0.01	0.1293
Sacrum	0.1506	0.00158	438	< 0.01	0.2637
Thoracic V.	0.7641	0.00148	467	0.02-0.01	0.2993
Lumbar V.	0.6940	0.00123	563	0.05-0.02	0.3305
Caudal V.	0.1089	0.00116	600	0.1 -0.05	------
Humeri	0.5116	0.000999	694	< 0.01	0.3723
Ribs	1.002	0.000929	746	0.02-0.01	0.3426
Scapulae	0.4129	0.000875	792	0.02-0.01	0.3782
Pelvis	0.6148	0.000794	873	0.05-0.02	0.3779
Paws	0.229	0.000702	900	NS	------
Skull	0.9738	0.000574	1200	0.1 -0.05	0.4026
Femora	0.5028	0.000557	1245	NS	0.3977
Mandible	0.4063	0.000156	4428	NS	0.5145
Radii	0.08362	0.000109	6330	NS	0.4392
Tib.-Fibulae	0.2928	0.0000978	7080	NS	0.4159
Ulnae	0.08285	0.0000195	35550	NS	0.4412
Cervical V.	0.4042	0.0000145	48000	NS	0.4246

* a = % of injected U/part

** t = t in days

NS = Not Significant

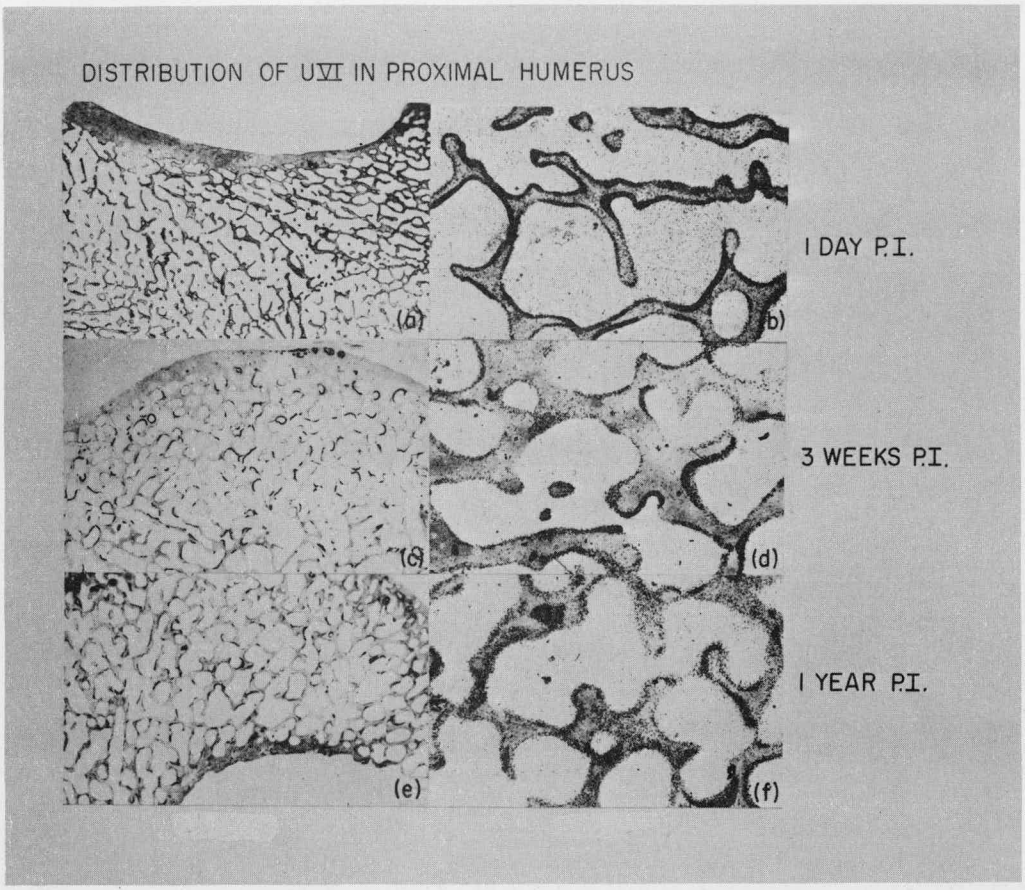

Figure 1. NIAR of 300 μm thick sections of methylmethacrylate embedded bone sections obtained from the proximal humerus. Low magnification (∿ 3.5 x) images a, c, e show the transition of an initially heterogeneous surface deposit to a "hot spot" surface deposition in which dense deposits are diminished as a function of time in number but not in intensity. Higher magnification (∿ 50 x) (b, d, f) emphasizes the heterogeneous character of the deposits and a gradual redistribution from surfaces to trabecular bone volume.

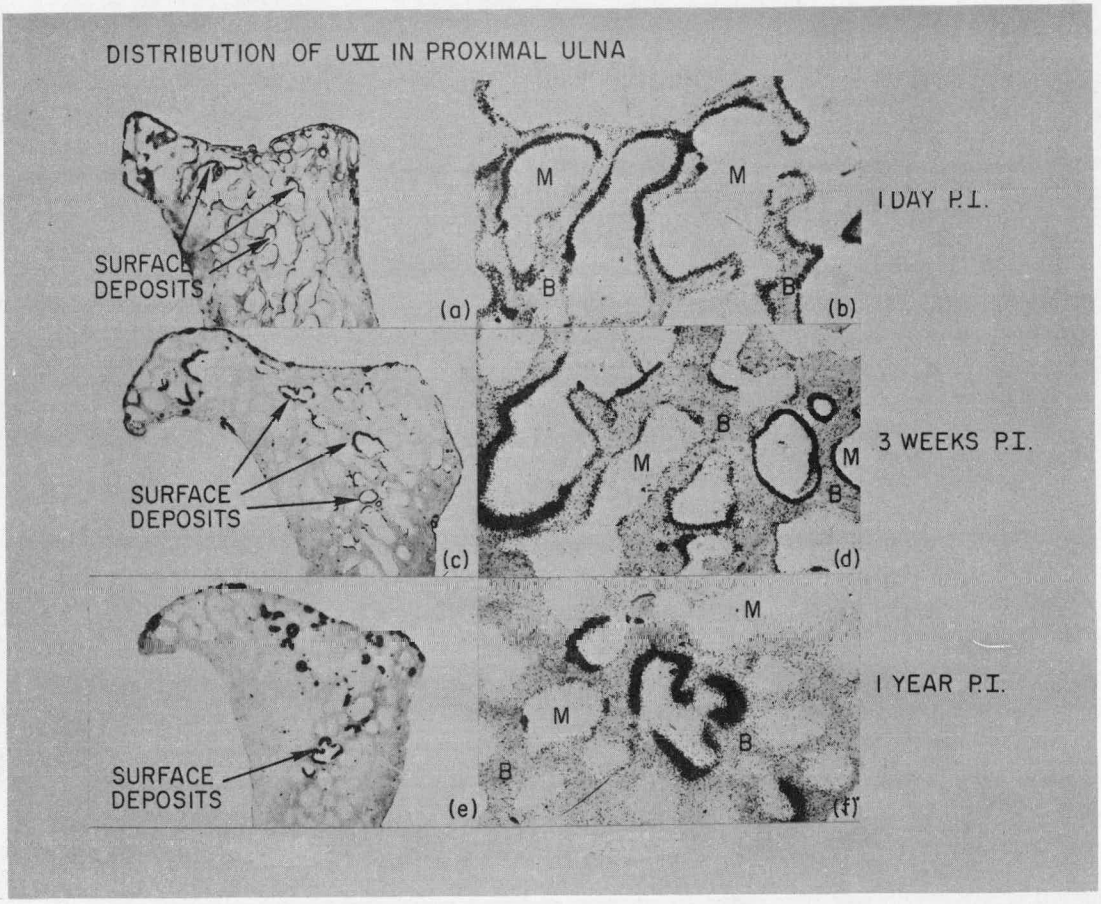

Figure 2. NIAR of sections obtained from the proximal ulna. Times P.I. and magnification are those of Fig. 1. Images reflect the lower concentration of U in the ulna as compared to the humerus. Surface deposits are strongly heterogeneous with dense deposits appearing at 1 year P.I.. A shift of U from surfaces to the trabecular volume is visible. M = Marrow; D = Bone.

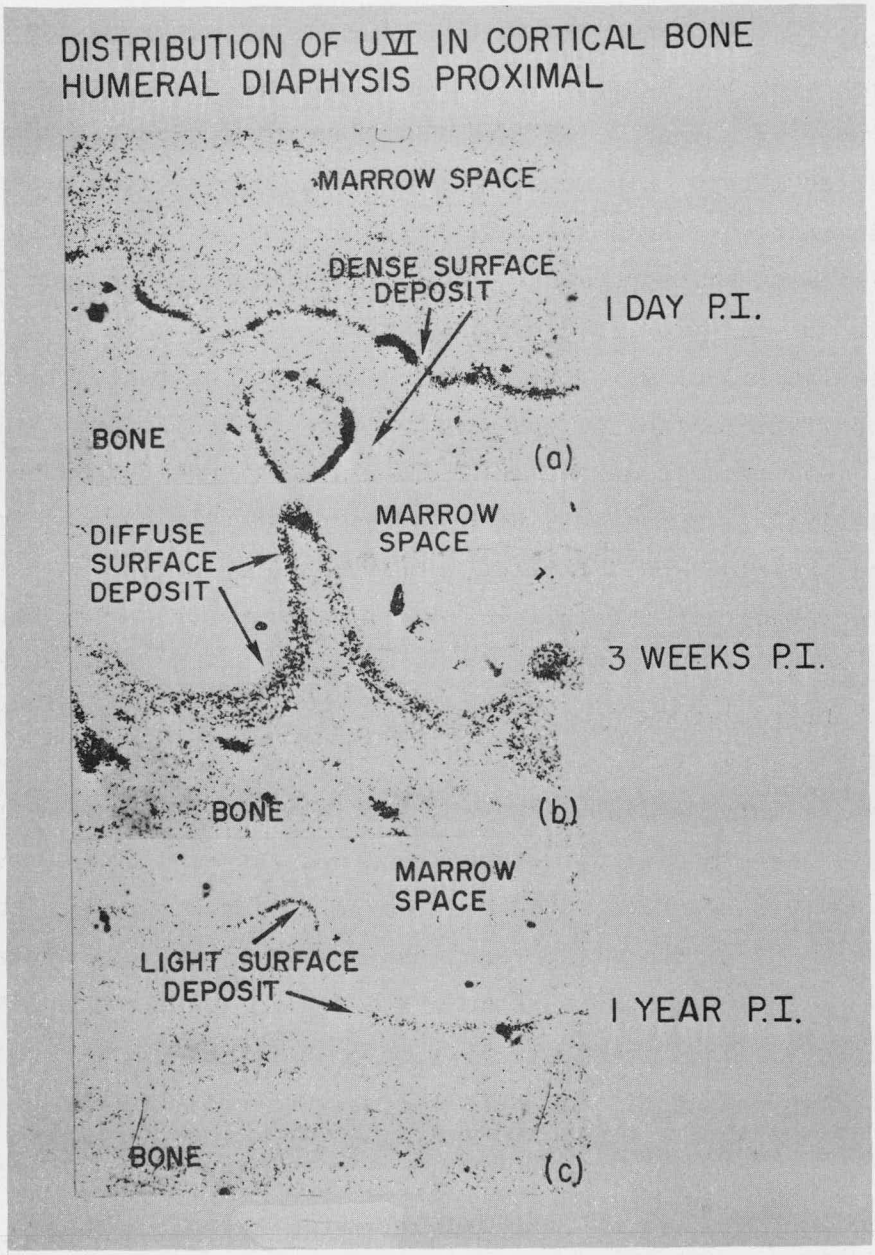

Figure 3. NIAR obtained from cortical bone of the humeral, proximal diaphysis. Initially U is seen on endosteal and periosteal surfaces and lining the Haversian canals. As a function of time P.I., surface labels become first diffuse and then light. During the first year P.I., the cortical bone aquires a light but quite uniform volume deposit.

at longer times P.I.. A similar distribution is observed in the ulna (Fig. 2) except that the average track density (which is proportional to the average concentration) is lower than in the humerus. There was relatively little redistribution from the surface to the bone volume as a function of time post injection. By 1 year P.I., isolated trabecular surfaces are still heavily labelled with U. In cortical bone (Fig. 3) endosteal, periosteal, and Haversian canal surfaces are intensely labelled initially and this deposit also is quite heterogeneous. As surface deposits decrease in number the bone volume acquires a low, diffuse concentration of uranium.

The distribution of U in the skeleton seen at increasing times post injection is consistent with the observation made by Neuman nearly thirty years ago that UO_2^{++} was capable of replacing Ca^{++} on the surface of the hydroxyapatite crystal (2). Since this reaction is reversible, deposition and/or loss of U from the skeleton would reflect normal equilibrium exchange reactions, the fate and turnover of the crystal(s) as well as the vascularity and bone turnover in localized areas of the skeleton. The size of the UO_2^{++} ion prohibits its entering the internal domain of the crystal lattice and thus it remains on crystal surfaces where it is subjected to ion exchange reactions with the extra mineral-extra cellular milieu of bone. The initial very dense surface deposits may mark areas where active Ca^{++} deposition was occurring as U was introduced, whereas the diffuse deposits, which become more predominant at long times post injection, result from competing reactions between the bicarbonate ion in the extracellular compartment and the phosphate ion on the surface of apatite crystals for UO_2^{++}. Thus, the distribution of U in the skeleton at any time post injection is the result of three factors, vascularity, bone turnover and localized ion exchange reactions.

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EARLY RETENTION AND DISTRIBUTION OF INJECTED ^{224}Ra IN BEAGLES*

R. D. Lloyd, C. W. Mays, G. N. Taylor, D. R. Atherton,
F. W. Bruenger, and C. W. Jones

Five adult beagles, averaging 21 months of age, were each given an intravenous injection of 10 μCi ^{224}Ra chloride/kg. Injected daughter activities were about 0.98 (^{212}Pb) and 0.95 (^{212}Bi) of the Pb/Ra and Bi/Ra ratios at transient equilibrium. The animals were sacrificed by exsanguination at 0.04, 0.14, 0.34, 1.0 and 3.0 days after injection, and serial gamma-ray counting of selected bones and soft tissues was begun a few minutes after death and continued for several days. Biological retention of ^{224}Ra averaged 49% in the skeleton (37 to 60%), and soft tissue retention decreased from 61% at 0.04 d to 7% at 3 d. At death there was an excess of Pb over Ra in red cells (~200 times), a small excess of Pb/Ra in liver, an excess of Bi over Ra was found in kidneys (4 to 9 times) and there was a deficiency of both daughters in eyes and bone. Relative to the values established at transient equilibrium, the Pb/Ra and Bi/Ra at death in the eyes remained at about 0.2 and 0.1, respectively. In bone, however, the Pb/Ra and Bi/Ra ratios increased regularly with time between injection and death (0.04 to 3 days) from about 0.3 to 0.9 and from 0.2 to 0.7, respectively. Biological effects have been observed in the skeleton, kidneys, eyes, and livers of persons injected with ^{224}Ra.

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*Abstract, Health Physics 35: 895 (1978).

GAMMA-RAY SPECTROMETRY OF HUMANS

Ray D. Lloyd, Charles W. Mays, and David H. Taysum

SUMMARY: A human total-body counter was designed and built with two 20 x 10 cm NaI(Tl) crystals suspended over an "isoresponse surface" upon which the subject reclines. This surface is curved from head to knee and from left to right, so that a gamma-ray emitting object is detected with equal efficiency when placed anywhere upon it. The positioner and detectors are housed in a low background enclosure constructed of steel 31 cm thick with a graded inner lining of lead + cadmium + copper. Calibration of the system was accomplished by administering trace amounts of various radionuclides to 48 human subjects of various sizes, ranging in age from 4 to 80 years. Counting rates per retained μCi at 0.53, 0.66, 1.53, and 2.75 MeV (^{83}Rb, ^{137}Cs, ^{42}K, and ^{24}Na) were determined as a function of body size and were compared with counting rates per μCi of corresponding emitters centered in a polyethylene cylinder of radius 10.3 cm. Limits of detection, corresponding to 3 times the standard deviation of a 50 minute background, were 170 nCi ^{90}Sr (via Bremsstrahlung x-rays), 0.78 nCi ^{131}I, 0.48 nCi ^{83}Rb, 0.52 nCi ^{137}Cs, 4.9 nCi ^{40}K (or 5.8 g of natural potassium), and 1.7 nCi ^{222}Rn.

INTRODUCTION

A human total-body counter which employed a single 20 cm x 10 cm NaI(Tl) crystal and an Argonne-type chair positioner was put into operation at the Radiobiology Laboratory, University of Utah, in 1962. Extensive use of this facility (Lloyd, *et al.*, 1968 a & b, 1969, 1970, 1973 a & b, Maletskos, *et al.*, 1967, Pendleton, *et al.*, 1963 a & b, 1965, Zundel, *et al.*, 1969) for biomedical research, monitoring of fallout levels, and for health physics purposes indicated that despite the obvious utility of the system, there were certain intrinsic limitations which could be eliminated by a thorough redesign.

Construction of a new laboratory building for our group provided the opportunity to make the proposed improvements.

ENVIRONMENT AND SHIELDING

The low-background enclosure for the new total-body counter is located on the ground floor of a one story concrete building at an elevation of about 1500 meters above mean sea level. Shielding provided by the building consists of reinforced concrete (Lloyd 1976) with a roof 20 cm thick and walls 30 to 60 cm thick. The low-background enclosure was constructed of solid, rectangular steel plate from the battleship U.S.S. Indiana, launched in 1941, four years before the first nuclear explosion. Walls, floor, and ceiling of the steel room are 31 cm thick. Choice of the unusually thick steel plate was dictated in part by the close proximity to an intermittently operated accelluator (maximum energy = 10 MeV) which is used in radiation therapy. Access to the steel room is by way of two adjacent doors, each 80 cm wide, 200 cm high, and 31 cm thick, which swing on hinges and are easily opened without power assistance.

Welding was done in an atmosphere of inert argon gas to eliminate the use of radioactive welding flux, and the welds were all on the outside of the room. Following erection of the shielded enclosure, the steel was cleaned by sandblasting and by washing with a chelating agent (EDTA). It was then enclosed with polyethylene sheeting, and the laboratory building was constructed around it.

Interior dimensions of the steel room are 370 cm long, 260 cm wide, and 240 cm high. The inside surface of the steel is lined with 3 mm Pb, plus 0.8 mm Cd, plus 0.8 mm Cu to reduce the amount of background and scattered

radiation which is detected (see discussion on page 264 of Whole Body Counting, Vienna: IAEA, 1962), and the inside copper finish is waxed to maintain a pleasing appearance.

Our specifications regarding the handling of the steel plate forbade the use of magnets, and it was our understanding that warships in service were demagnetized periodically. However, the steel was in storage for nearly 3 years before the shielded enclosure was constructed, and the ship had been out of service for several years prior to the time at which the plate was made available. Therefore, residual magnetism would not have been unexpected. Measurements made within and outside the completed steel room indicated that the total magnetic effect within the 1.5×10^5 kg steel room was about equal in magnitude to the earth's magnetic field, roughly 0.5 gauss. Compared to the performance of a 20 x 10 cm NaI(Tl) crystal placed exactly at the volumetric center of the room, a serious perturbation of relative counting rate and output pulse height of a 0.2 μCi ^{137}Cs source taped to the crystal face was discovered with the crystal in only one corner location (about a 4% shift). Consequently, it was decided to keep the detectors for the human total-body counter always at least 1 meter away from each interior surface since no significant effects from the magnetic field were detected at this distance.

Clean air, which has been pre-filtered mechanically and electrostatically, is drawn from the laboratory into the steel room through a 15 cm thick Argonne-type (HEPA) absolute filter to trap the gamma-emitting daughters of ^{222}Rn (radon). Initially, the air turnover rate within the steel room was equivalent to about 20 changes per hour. Later, this was decreased to about 7 changes per hour as a consequence of a noise reduction program. Background counting

rates, especially with reference to the gamma-emitting daughters of ^{222}Rn, were virtually unchanged by this modification. The ventilation system keeps the laboratory building under positive air pressure so that radon generated in the concrete walls, floor, and ceiling tends to be forced outside the building.

Subjects can be viewed on closed circuit television during the counting period. An intercommunication system allows two way voice access, as well as FM radio or stereo tape entertainment. Of particular value have been the tapes of fairy tales and adventure stories that encourage children to remain in the positioner for counting times up to an hour when necessary. The interior is illuminated by three 60 watt incandescent bulbs which, with the bright copper surface, results in an attractive, cheerful enclosure. In addition, subjects know that the door can be opened from the inside without assistance. As a consequence of all these factors and the relatively large size of the steel room, claustrophobia has not been a significant problem.

POSITIONER DESIGN

Our concept for a human positioner with an isoresponse geometry was developed from an early isoresponse positioner for beagle total-body counting (Lloyd et al., 1962, 1976b). Similar designs for human counting have been reported by Chhabra (1964) and by Joyet and Baudraz (1967, 1968). With a single detector, however, an isoresponse surface approximates the inside surface of a hollow sphere (Belcher and Robinson, 1965). In order to put the subject close enough to the detector to achieve reasonable counting rates, the resulting curvature of the positioner becomes too severe for the comfort of many adults. Chhabra (1964) used a 50 cm radius of curvature, which seemed to conform adequately to the typical 55 kg 167 cm tall Indian adult, while

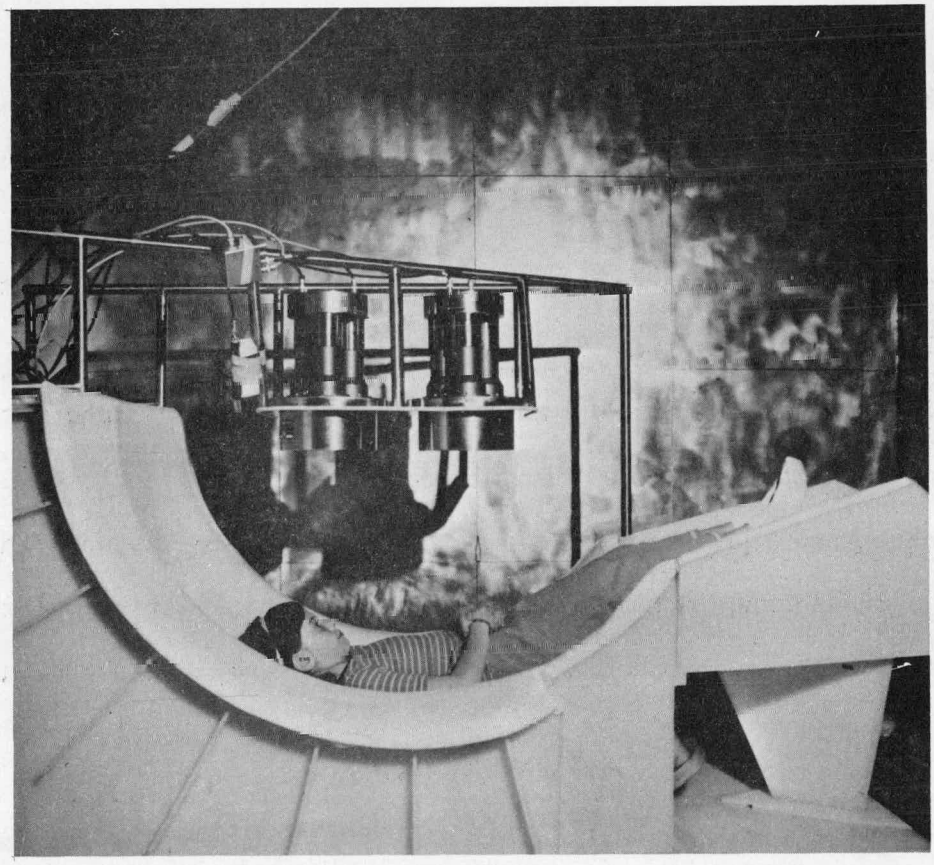

Figure 1. Photograph of the positioner showing the two 20 x 10 cm NaI(Tl) crystals suspended above an isoresponse surface upon which the subject is positioned. The child (SM) shown here was an 8-year old girl, 133 cm tall, weighing 26 kg.

Joyet and Baudraz (1967, 1968) used a radius of 57 cm. In both cases, however, the positioner was curved in just one plane, so that the surface approximated the inside of a transverse cylinder rather than a sphere. The isoresponse curve was located only along the center line, and the detection efficiency decreased if the subject moved to the side. With a radius of curvature much less than about 100 cm, the legs below the knee cannot conform comfortably to the curve. Both Chhabra and Joyet and Baudraz elected to exclude the lower leg from their curves.

With our two detectors, the isoresponse surface approximates the section of a torus. The resulting curvature is not as pronounced as that of a spherical section at a corresponding distance from a single detector. A larger volume of scintillator provides an increased counting rate when compared to a single crystal at the same distance, making it possible for equal counting efficiency to utilize a positioner of larger effective radius, which is more comfortable for the subject.

Our actual positioner is shown in Figure 1, with a scale drawing of its most essential features in Figure 2. The bottom of the positioner is 59 cm below the plane in which lie the faces of two 20 cm x 10 cm NaI(Tl) crystal detectors, whose cylindrical axes are 30 cm apart. The isoresponse surface was established experimentally so that a ^{137}Cs source 10 cm above the surface gave the same counting rate from head to knee and from side to side. This corresponded to the center line of a person averaging 20 cm in thickness. The resulting surface, with a mean radius of curvature from head to knee of about 60 cm, was comfortable for children (2 years and older), adults up to 200 cm tall, pregnant women, and patients of non-standard body configuration.

The positioner was constructed (Figs. 1 and 2) of 6 mm thick polyethylene

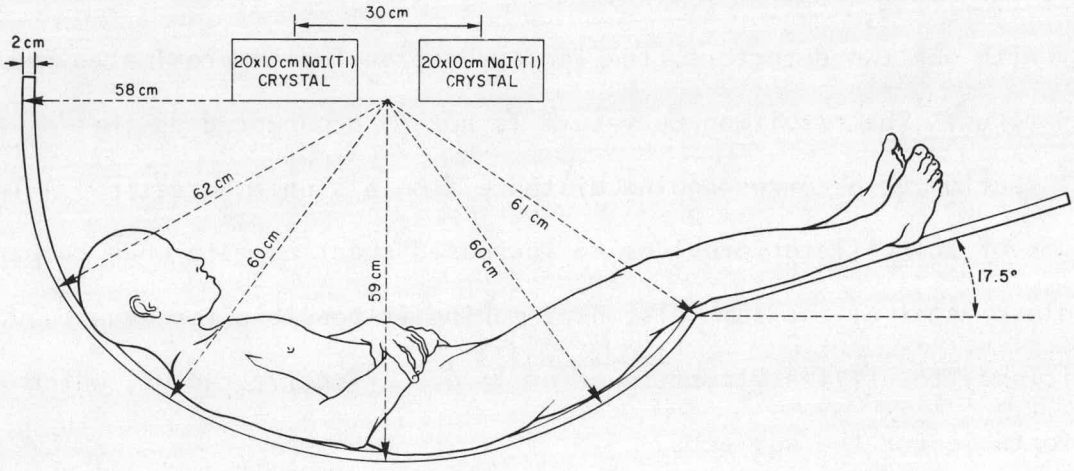

Figure 2. Cross-sectional sketch of the Utah total-body counter. Note that the 2 cm thick foam padding is compressed by the subject at a number of weight-bearing locations.

sheeting using full size templates cut from masonite as the pattern for the doubly-curved surface on which the subject reclines. A singly-curved surface extending distally from the positioner at an angle of about 17.5° above the horizontal was designed for a lower leg support. Polyethylene was selected as a non-radioactive construction material of low atomic number. However, to avoid the gamma-rays from neutron capture by hydrogen in the polyethylene, thin, stainless steel sheets would be used if another positioner were to be built at this altitude. The framework was constructed of stainless steel tubing of 2.54 cm outside diameter, with silver soldered joints, to eliminate the use of welding rods that frequently contain variable amounts of Th, Ra, and K (Marinelli et al., 1962). The framework also supports a 3 mm thick steel plate, 64 cm x 45 cm, having two 22 cm wide slots into which the NaI (Tl) crystals can be inserted to place them reproducibly above the positioner. All materials of which the positioner was constructed had been subjected to gamma-ray spectroscopy prior to use. No gamma-ray emitters could be detected in the polyethylene sheeting, polyethylene rod used for joint fabrication, stainless steel tubing, silver solder, steel plate crystal support, 2 cm thick foam padding, or the white (first cover) or bronze (second cover) naugahide, although the green naugahide initially tested, but not used, exhibited significant levels of radioactivity.

When the positioner had been completed, but before the padding and cover were installed, a grid, which had a 10 cm rectangular spacing, was drawn on the doubly curved surface. A point source of ^{137}Cs was counted 10 cm above each grid intersection, and it was found that the actual positioner, indeed, approximated closely an isoresponse surface, with respect to the two crystals. For the 102 separate grid intersection positions, the standard deviation among the counting rates was ± 4.8%.

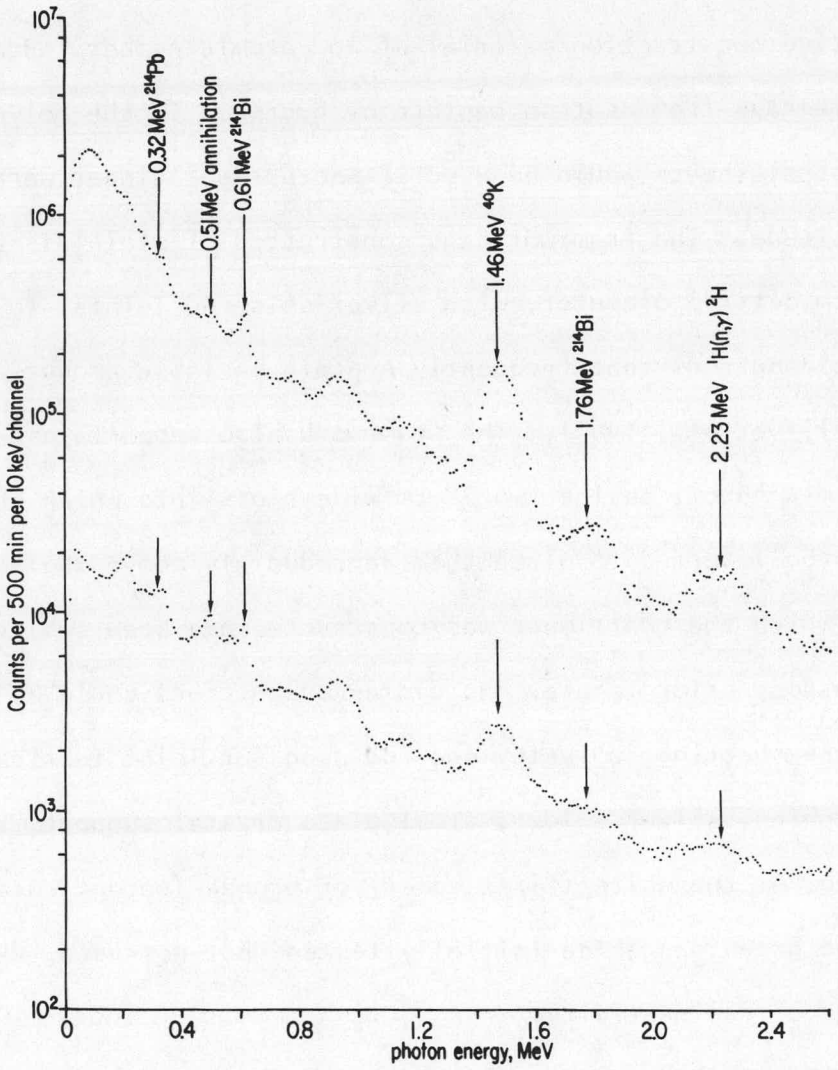

Figure 3. Background spectra recorded for 500 minutes by a single 20 x 10 cm NaI(Tl) crystal inside (lower curve) and outside (upper curve) the 31 cm thick steel room.

BACKGROUND

The background counting rate inside the steel room is between one and two orders of magnitude less than that measured within the laboratory building just outside the shielded enclosure (Fig. 3), the exact value depending upon the energy region of the spectrum which is considered. Photopeaks corresponding to gamma-rays from the radioactive decay of ^{40}K and nuclides in the ^{226}Ra series appear in the background spectra taken inside and outside the steel room. It has been reported (Joyet and Baudraz 1968, May and Marinelli 1962, Schmier 1969) that whereas the background recorded by a shielded NaI(Tl) crystal above about 3 MeV is mainly due to the cosmic radiation, the lines in the spectum representing ^{40}K, ^{214}Pb, and ^{214}Bi largely result from radioactivity in the crystal assembly, principally the photomultiplier tubes. Data displayed in Fig. 4 indicate that no radioactivity was brought into the steel room as a result of the installation of the Pb + Cd + Cu lining. As also was observed by Marinelli et al. (1961), and by May and Marinelli (1962), the low energy background was diminished significantly by the addition of a thin Pb layer inside the steel. In this case (Fig. 4), there was nearly a factor of 2 reduction below about 0.2 MeV. For the two 20 x 10 cm NaI(Tl) crystals, the integral counting rate of background between 0 and 2 MeV is about 1800 counts per minute. Corresponding background data for individual areas of the spectrum are exhibited in Table 1. In general, background counting rates in various regions of the spectrum within the 31 cm thick steel room average about 66% per crystal of that measured in our old steel room, with 13 cm thick walls covered on the outside with 1 cm of Pb. Individual ratios of background were 59% at 0.3 MeV, 65% at 0.66 MeV, 68% at 1.76 MeV, 68% at 1.0 MeV, and 73% at 1.46 MeV.

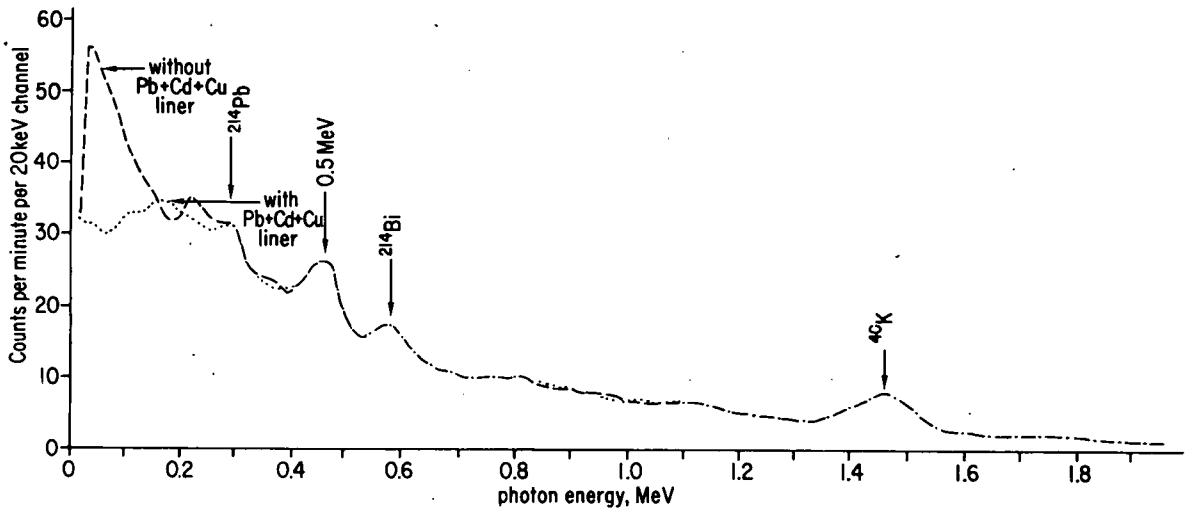

Figure 4. Background spectrum recorded for 400 minutes by a single 20 x 10 cm NaI(Tl) crystal placed at the volumetric center of the 31 cm thick steel room before and after the installation of the Pb + Cd + Cu lining.

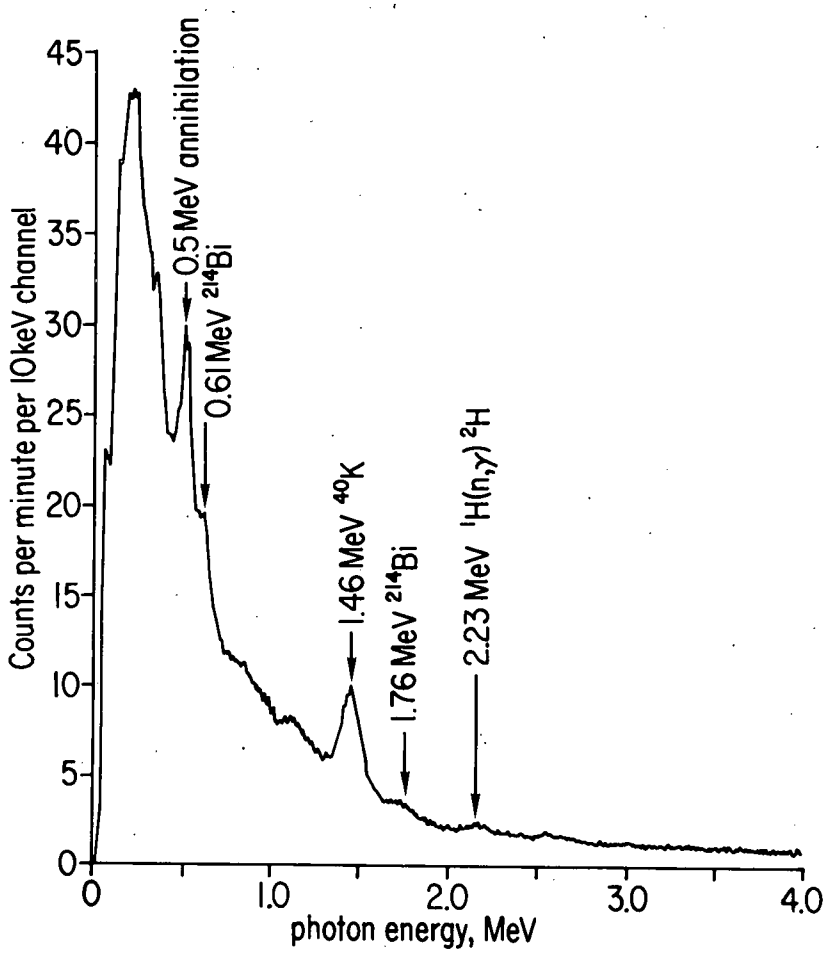

Figure 5. Background spectrum recorded for 400 minutes inside the 31 cm thick steel room by two 20 x 10 cm NaI(Tl) crystals above the isoresponse positioner (see Fig. 1).

Table 1. Background and standard source counting rates in selected regions of the energy spectrum for the two 20 x 10 cm NaI(Tl) crystals utilized in gamma-ray spectrometry of humans at The University of Utah.

Emitter	Photon Energy, MeV	Counting Band, MeV	Background Count/min (cpm)	Source (cpm/nCi)	Detection Limit = 3Σ, (nCi)**
^{90}Sr + ^{90}Y*	*	0.06-0.15	332	0.046	170
^{131}I (thyroid)†	0.36	0.33-0.40	140	6.404	0.78
^{83}Rb	0.53	0.49-0.57	202	12.620	0.48
^{137}Cs	0.66	0.62-0.71	187	11.060	0.52
^{40}K	1.46	1.39-1.52	117	0.943	4.9
^{222}Rn (via ^{214}Bi)	1.76	1.67-1.85	63	1.953	1.7

* Bremsstrahlung x-rays, continuous spectrum of 0 to 2.27 MeV in energy.

** Corresponding to 3 standard deviations of a 50 minute background count.

† Inside an ORNL neck phanton (designed at the Oak Ridge National Laboratory): The other sources were centered inside our polyethelene phanton No. 3 (see Table 2).

A distinct photopeak was observed at 2.23 MeV in the background spectrum (Fig. 5) and especially in the spectra recorded for humans. It was determined that this was a result of the gamma-ray produced in the capture of a neutron by hydrogen = $^{1}H\ (n,\gamma)\ ^{2}H$. There was sufficient hydrogen-containing material inside the steel room to moderate and capture enough environmental neutrons to produce a "hydrogen peak" at 2.23 MeV. Removal of the polyethylene part of the human positioner reduced the hydrogen photopeak to virtually undetectable levels.

The effect of this hydrogen capture gamma-ray on the total spectrum for a 70 kg subject was investigated. Nineteen steel cans, 16 cm in diameter and 19 cm high, were each filled with about 3.32 liters of distilled water (aged at least one month to ensure that the radon content was negligible) so that the total mass of water was 63 kg and the total mass of water and steel was 70 kg. A calculated total of 7 kg hydrogen was equal to that in the reference 70 kg human that is 10% hydrogen. The cans were arranged in the human positioner in such a way as to approximate the distribution (Andrasi and Kotel 1975) of body mass in a 70 kg man.[1] This anthropomorphic phantom or man-made-of-cans was christened "Can Man" and resembled in appearance the notorious Tin Woodman of Oz (Baum 1899). A Can Man spectrum was accumulated for a 400 minute counting period, and the pulse-height analyser subtracted from it, channel by channel, a background spectrum which was run for an equal length of time with nothing in the positioner. An example of this net spectrum is shown in Fig. 6, which exhibits several very interesting features. The photopeak at 2.23 MeV is prominent, but the Can Man seems to have had no effect on

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(1) Ten percent head and neck, 60% trunk and arms, 20% thighs, and 10% lower legs and feet.

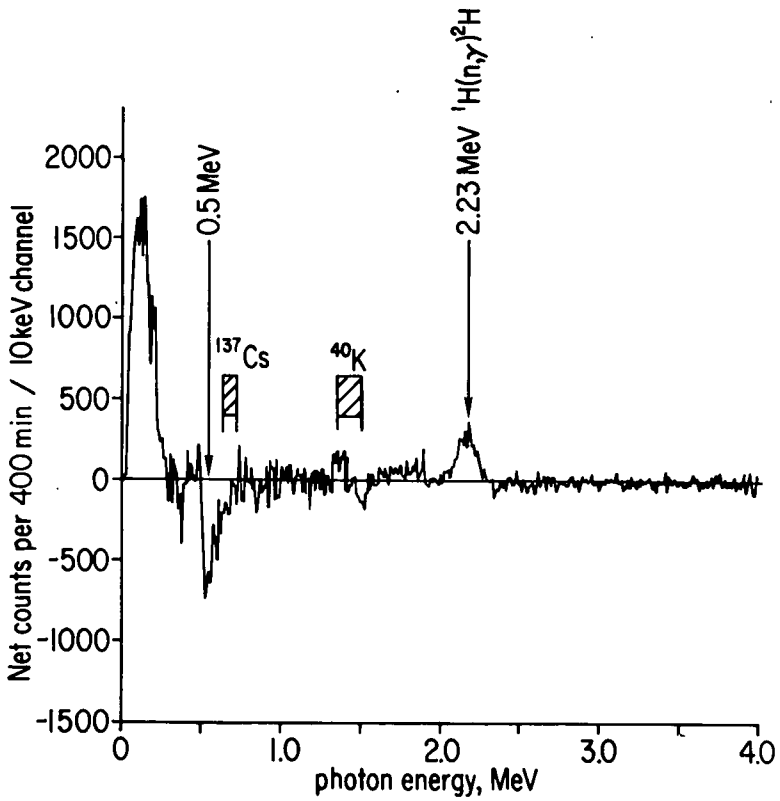

Figure 6. Spectrum of "Can Man," 63 kg of distilled water in 19 steel cans, in the positioner (see Fig. 1), recorded for 400 minutes, from which a background spectrum has been subtracted channel by channel. The background spectrum was recorded for an equal length of time under identical conditions, except without Can Man.

the spectrum above the peak. Below about 0.3 MeV, the net counting rate was increased dramatically, mainly due to the Compton scattering of the 2.23 MeV photons. Between about 0.6 and 2.0 MeV, the net counts per channel seem to be about evenly balanced in magnitude and sign (+ and -). In the two regions of the spectrum of particular interest which are integrated for ^{137}Cs and ^{40}K (indicated by shading), the total net counting rates approach zero (this effect is more striking in a number of separate runs considered together rather than in just a single example, but the trend can be recognized in Fig. 6). There is a distinctive "negative peak" in the net spectrum at about 0.5 MeV. Can Man seems to exert two opposing effects upon the background spectrum: (1) Increasing the counting rate at 2.23 MeV and below as a result of additional neutron capture in hydrogen, and (2) decreasing the counting rate by shielding of the detectors. Effect #1 is dominant at 2.23 MeV and below 250 keV; effect #2 is dominant at about 0.5 MeV, and the two effects are roughly equal in other regions of the spectrum. Additional runs made in a similar fashion, but with 70 kg sulfur or 70 kg graphite in place of the Can Man, confirmed that the 2.23 MeV photopeak in Can Man resulted from the presence of additional hydrogen and verified the above assumptions concerning the shielding of the crystals.

Net counting rates in the 2.23 MeV photopeak were examined as a function of body mass for 26 people with various body configuration and size. Counting rates increased with increasing body mass, ($P<0.001$, with a correlation coefficient of $r = 0.79$), because of increasing hydrogen content with increasing body mass. However, overall net counting rates were so low that statistical accuracy (S.D.) of an individual measurement was poor, between about ± 11% and ± 54% in typical best and worst cases (11.5 and 2.8 net cpm).

Therefore, counting rates in the 2.23 MeV photopeak are not high enough to yield accurate estimates of total-body hydrogen in a reasonable counting time, yet the effects on the spectrum of the neutron-capture gamma-ray of hydrogen are not low enough to be ignored completely. A solution which has been utilized is to employ a Can Man net spectrum as an additional standard for correcting the counting rates in human spectra at each energy for the contributions of the various emitters observed.

When Can Man was measured in our old total-body counter, it was discovered that the counting rate at 2.23 MeV was nearly 3 times lower than in the newer configuration. Even when a correction was made for the different counting efficiencies which corrected for the volume of scintillator, the resulting difference between the two steel rooms was still considerable. As a result, measurements of environmental neutron levels were made within and outside the 31 cm thick steel room, using a Texas Nuclear Co. model #9140 Nemo spherical neutron dosimeter system, which employs as a detector a 4 mm x 8 mm ^{6}Li (Eu) crystal surrounded by a 25.4 cm diameter solid polyethylene spherical moderator. It was found that the counting rate of neutron background between about 0.2 MeV and 14 MeV inside the shielded enclosure was from 20% to 34% higher than that measured outside the room in repeated measurements.

The additional neutrons inside the steel room are believed to result from the interaction of cosmic ray muons within the massive iron shield (Gold 1973, ICRU 1972, Rundo and Bunce 1966, Tanaka et al., 1965). Similarly, Peterson et al. (1965) discovered a neutron background inside their shielded enclosure and reported a greater neutron production by cosmic ray muon interactions with a high atomic number (Z) material such as Pb than a low Z material such as H_2O. Evaporation neutrons arise from the interaction of cosmic ray nucleons

and muons with nuclei (ICRU 1972, Marinelli et al., 1962, May and Marinelli 1962, 1964, Tongiorgi 1949). Being of cosmic-ray origin, this effect increases greatly with altitude. It is much larger at our laboratory (1500 meters) than at sea level. Thick shields of iron, lead or other high Z materials produce more than thinner shields or those of lower Z materials. The resulting neutrons are not absorbed strongly by iron or lead (Sychev 1967). It seems likely that the muon component of the cosmic radiation (Roos 1961) is at least partially responsible for the production of 0.5 MeV photons (ICRU 1972, Marinelli et al., 1962, May and Marinelli 1962) that are partially shielded from the crystals by the bulk of Can Man (as illustrated in Fig. 6) through the reactions:

$$\mu^+ \rightarrow \beta^+ + 2\nu$$

$$\beta^+ + \beta^- \rightarrow 2\ (0.51\ \text{MeV}\ \gamma)\ .$$

PERFORMANCE

Whereas in our old human positioner we were able to count satisfactorily infants up to about 3 months of age (Pendleton et al., 1965), children over 4 years of age, and adults, the isoresponse positioner enables the measurement of children as young as 2 years. This is because the counting rate of the child is relatively independent of position as long as his body is in contact with the doubly curved surface and, except for movement off the surface and toward the detectors, it is not critical that the child remain motionless during the counting period. For positioners not designed with an isoresponse surface, including those with an isoresponse curve only along the center line, movement toward the outer edges of the positioner may seriously decrease the counting rate. In addition, persons of non-standard body configuration with scoliosis or contractures from the effects of diseases such as

muscular dystrophy, cannot always be positioned comfortably along the center line of a human positioner. Counting rates are not affected significantly when the non-standard body reclines in contact with the isoresponse positioner, however, regardless of the way in which the subject must be arranged on its doubly curved surface. It is difficult for women in the final stages of pregnancy to remain in a conventional chair positioner for a lengthy counting time, but the much more gentle overall curvature of the new positioner is comparatively comfortable.

The total-body spectrum of a man containing about 8 kg hydrogen, 0.128 μCi ^{40}K (151 g of total potassium), and 0.124 μCi ^{137}Cs is shown in Fig. 7.

CALIBRATION

Counting rates per μCi of activity in a human subject were estimated in two ways. Primary calibration (Rundo 1962) was accomplished by administering trace amounts of ^{83}Rb, ^{137}Cs, ^{42}K, or ^{24}Na to people of various sizes and recording their spectra. Retained activity in each case was determined from excreta counting. Secondary calibration was done by means of a series of phantoms in which sources containing ^{210}Pb, ^{241}Am, ^{51}Cr, ^{85}Sr, ^{137}Cs, ^{54}Mn, ^{65}Zn, ^{40}K, ^{42}K, ^{226}Ra, ^{228}Th, or ^{24}Na were counted. These phantoms were constructed of laminated polyethylene, which has a density of about 0.94 g/cm^3. The six cylindrical phantoms were of slightly elliptical cross sections with a uniform height of 40 cm, but differed in their radial dimensions (see Table 2). Each phantom contains an axial tunnel about 4.5 cm in radius within which can be centered either (A) a 4.1 cm radius x 11.3 cm long Lucite cylinder containing an axial well, 1 cm in radius, extending into the cylinder 7.1 cm, within which a 10 ml glass ampoule can be positioned (Lucite has a density of about 1.2 g/cm^3), or (B) a cylinder, 4.1 cm in radius and 17.6 cm long, made of 3 mm

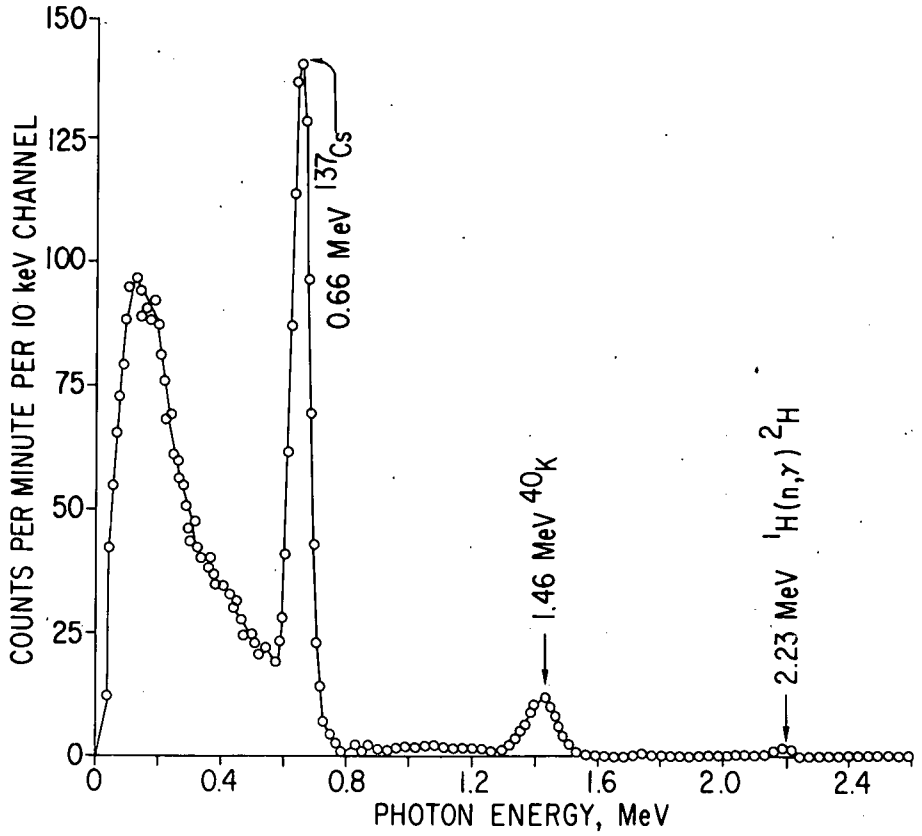

Figure 7. Total-body gamma-ray spectrum of a man containing about 8 kg hydrogen, 0.128 μCi ^{40}K (151 g of natural potassium) and 0.124 μCi ^{137}Cs. Background has been subtracted.

thick Lucite and containing a measured amount of reagent grade potassium chloride (about 430 g K or 0.365 μCi ^{40}K). For counting, phantoms were placed in the human positioner, laterally centered, and along the position of a subject's thighs (Figs. 1 and 2).

In vivo studies. An opportunity for the primary calibration of our system occurred when, in connection with another study (Lloyd et al., 1973a), 38 persons of various ages, heights, weights, and body configurations were given orally, in a few ml of sterile solution, a double tracer containing about 6 μCi ^{83}Rb and 1 μCi ^{137}Cs. Control subjects less than 18 years of age received only half as much of each radionuclide. The individual ingestion solutions were assayed by gamma-ray spectroscopy for ^{83}Rb and ^{137}Cs content before administration. Each empty vial was also counted after administration, and the ingested activity was assumed equal to the difference.

Total collections of urine were made during the first 2 days of the study, and the ^{83}Rb and ^{137}Cs in each day's sample was determined. When a subject had defecated during a 1-day collection period, the day's urine was assumed to account for 80% of the excreted ^{83}Rb and 85% of the excreted ^{137}Cs (Lloyd et al., 1968a). Counting rates of each subject were determined immediately at about 10 minutes after ingestion and at the end of each of the two excreta collection periods. Standard sources containing known activities of ^{83}Rb or ^{137}Cs or ^{40}K were also counted daily inside phantom #3 (Table 2) to enable the correction of subject counting rates in each energy band for the contribution from the other emitters. Retained activities of ^{83}Rb and ^{137}Cs were determined from excreta counting and were compared with corrected net counting rates of ^{83}Rb and ^{137}Cs in each subject relative to the respective net counting rate per μCi in the phantom.

Table 2. Characteristics of the polyethylene phantoms used in the calibration study.

Phantom Number	Minor Radius,* cm	Height, cm	Mass,** kg	Total Absorber Thickness,† cm		Radially Weighted†† Absorber Density (= ρ in g/cm³)
				Lucite (ρ = 1.2)	Polyethylene (ρ = 0.94)	
1	6.20	40	3.4	3	2	1.096
2	8.25	40	6.8	3	4	1.051
3	10.30	40	11.3	3	6	1.027
4	12.25	40	16.6	3	8	1.011
5	14.25	40	22.8	3	10	1.000
6	16.25	40	29.8	3	12	0.992

* Phantoms placed in the positioner with the minor radius perpendicular to its surface.

** Including the 4.1 cm radius x 11.3 cm Lucite cylinder and a hollow cylindrical Lucite spacer, 4.1 cm in radius, 14 cm high, and 3 mm thick.

† Radially.

†† For example, in phantom #3, the radially weighted density = (3/9)(1.2) + (6/9)(0.94) = (0.400) + (0.627) = 1.027.

As has been done by other investigators (Ben Haim and Dudley 1966, Marinelli 1966, Naversten 1966), the effective half-thickness (X) of each person was calculated from the weight in grams (W) and the height in cm (H):

$$2X = \sqrt{W/H} \qquad (1)$$

or

$$X = (1/2)\sqrt{W/H} \qquad (2)$$

If a person can be represented by a unit density cylinder of slightly elliptical cross sectional area W/H, its effective minor radius corresponds to half-thickness "X" in Equations 1 and 2.

The counting rate (R) in the primary photopeak, relative to that in phantom #3 per retained μCi in these subjects, decreased as an exponential function of half-thickness (X) such that

$$R = ae^{-kX} \qquad (3)$$

Statistical analysis indicated that the exponential constant "k" was significantly greater than zero for both ^{83}Rb ($P<0.001$) and ^{137}Cs ($P<0.001$). There was no significant difference between either the coefficients (a) or exponential constants (k) if the data for the 16 persons with muscle disease were considered separately from the data for the 22 persons without muscle disease (^{83}Rb: $P>0.2$; ^{137}Cs : $P>0.1$).

When the relative counting rate per μCi in phantom #3 (Table 2) was taken as unity, the regression equation which described the relationship of relative counting rate (R) in the subject as a function of half-thickness (X) was for ^{83}Rb at 0.53 MeV:

$$R_{0.53} = 1.586\ e^{-(0.0436 \pm 0.0075)X} \quad (4)$$

and was for ^{137}Cs at 0.66 MeV:

$$R_{0.66} = 1.534\ e^{-(0.0374 \pm 0.0071)X} \quad (5)$$

Statistical analysis showed no significant difference ($P>0.2$) between either the coefficient or exponential constant for the ^{137}Cs equation derived for humans (Eq. 5) and the ^{137}Cs equation derived for phantoms of $R = 1.307e^{-0.026x}$, where (x) is the minor radius of the phantom. Also, there were no significant differences between the ^{83}Rb equation derived for humans (Eq. 4) and the equation for ^{85}Sr derived for phantoms of $R = 1.391\ e^{-0.032x}$. These 2 emitters were compared because their gamma-ray energies are quite similar (^{85}Sr = 0.514 MeV and ^{83}Rb = 0.53 MeV). Data exhibited in Figures 8 and 10 illustrate the resemblance of counting rates per μCi in persons and phantoms for ^{137}Cs, and for ^{83}Rb using data in phantoms for ^{85}Sr.

An additional calibration study was performed using ^{42}K[2] as listed in Table 3. Several authors have shown (Delwaide et al., 1962, Lloyd 1964, Marinelli et al., 1962) that for chair-type positioners, a 10 to 24 hour period is required for an administered ^{42}K activity to become equilibrated with body potassium for purposes of <u>in vivo</u> counting. Following an overnight fast, about 4 μCi ^{42}K in a few ml of sterile solution were given orally to each of the adult subjects. Two hours later, and before any excretion had taken place, the total-body spectra were recorded. Another total-body count was made at 24 hours after ingestion. The reference source originally containing 13.2 μCi ^{42}K was also counted in phantom #3 (Table 2) several times on both days of the

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(2) All counting rates and activites for ^{42}K were corrected for radioactive decay to a common time.

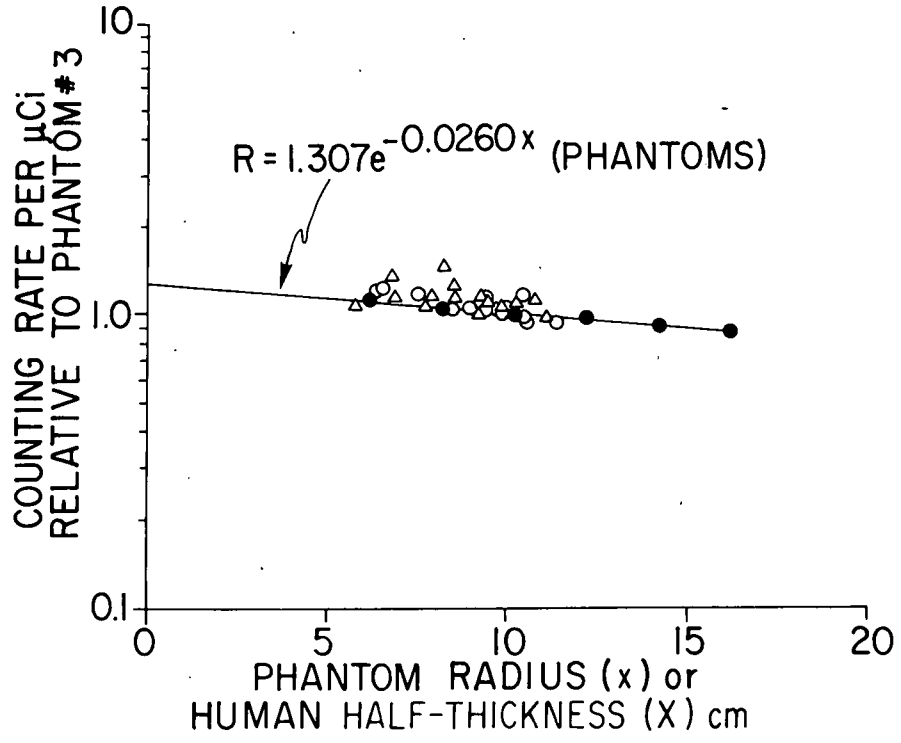

Figure 8. Relative counting rates per retained μCi ^{137}Cs in healthy persons (open circles), persons with muscle disease (triangles), and in the series of polyethylene phantoms (solid circles) shown as a function of effective body minor radius or phantom radius.

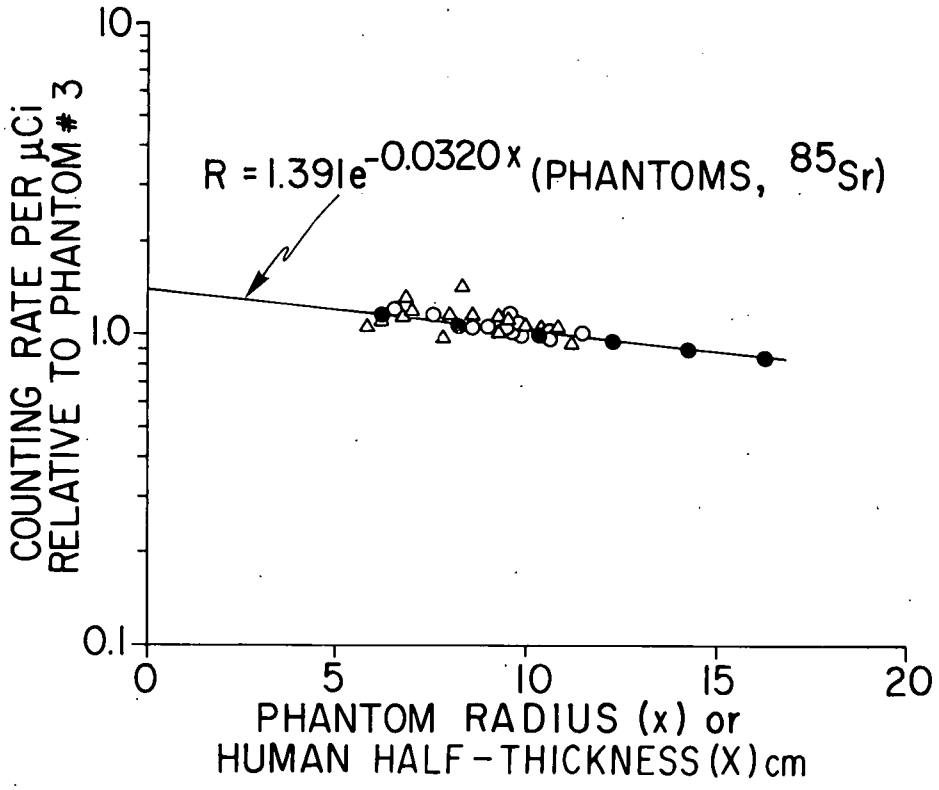

Figure 9. Relative counting rates per retained μCi ^{83}Rb (photon energy = 0.53 MeV) in healthy persons (open circles) and in persons with muscle disease (triangles) as a function of effective body minor radius. Also shown are similar data for ^{85}Sr (photon energy = 0.514 MeV) in the series of polyethylene phantoms as a function of phantom radius.

Table 3. Adults in ^{42}K calibration study.

Subject	Sex	Weight, kg	Height, cm	Half-thickness cm	[cpm/μCi in person / cpm/μCi in phantom]
SM	F	51.6	169.5	8.7	1.079
FB	M	56.6	175.0	9.0	1.048
NW	M	71.5	178.5	10.0	1.003
RL	M	73.7	171.0	10.4	0.949
DB	F	76.5	157.5	11.0	0.958
DA	M	89.5	175.0	11.3	0.933
RJ	M	90.5	176.5	11.3	0.928
TB	M	104.0	180.5	12.0	0.933
DB	M	114.2	181.0	12.6	0.919

study. Each of the 9 vials containing ^{42}K was counted before and after its contents were administered to a subject, and the ingested activity was assumed to equal the difference. In an earlier study (Lloyd 1964), it was found that for normal adults, an average of 4.55 ± 0.05% of ingested ^{42}K was excreted in the first 24 hours. Therefore, it was assumed that 4.55% of the administered ^{42}K was excreted also by the 9 adults in this study between the total-body counts made at 2 hours and 24 hours after ingestion.

A comparison of the relative counting rates at 2 hours and at 24 hours showed that for an individual the counting rate per retained μCi ^{42}K was rather constant, with about 1/3 of the values declining and about 2/3 increasing in the interval. The ratio of relative counting rate per μCi at 2 hours to that at 24 hours averaged 0.964 with a standard deviation of ± 0.046. Since the two sets of values were so similar, their average is shown in Table 3. The 2 hour value may have contained some error, since the 10 to 24 hour equilibration time of ^{42}K with body K had not elapsed, but no correction for ^{42}K excretion was necessary. However, the 24 hour value may have contained some error because of variability in actual excretion, but the equilibration of ^{42}K with body potassium was almost certainly complete.

Comparison of various relative counting rates (R) at 1.53 MeV as a function of half-thickness (X), yielded the following regression equation (Figure 10) for the 9 individuals in this study:

$$R_{1.53} = 1.525\ e^{-(0.0422 \pm 0.0066)X} \qquad (6)$$

There was no significant difference ($P>0.2$) between the corresponding equation for the 2 hour values and that for the 24 hour values, so that they were all combined in the derivation of equation (6). In contrast to the situation found

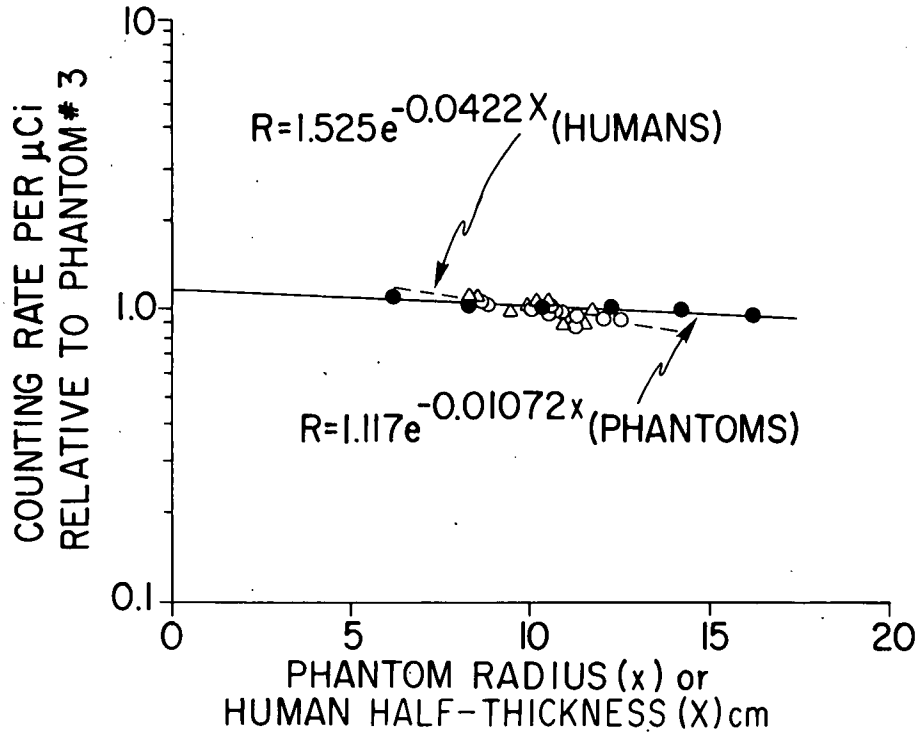

Figure 10. Relative counting rates per retained μCi ^{42}K in the 9 persons shown in Table 3 (open circles) as a function of effective body minor radius. Also exhibited as triangles are corresponding data for persons given ^{42}K in an earlier study (Lloyd 1964, Table 4). Solid circles show results of ^{42}K counting in the series of polyethylene phantoms (Table 2).

for ^{83}Rb and ^{137}Cs in which there was no significant difference between the regression equations for humans and phantoms, there was a significant difference ($P<0.001$) between exponential constants of the ^{42}K equations for humans (Eq. 6) and that derived for phantoms of $R = 1.117\ e^{-0.0107x}$.

Interestingly enough, the predicted values (Eq. 6) for the relative counting rates in this study were similar to those determined in our earlier work on ^{42}K in humans using a chair-type positioner (Lloyd 1964, Table 4). The regression equation derived for these data was:

$$R_{1.53} = 1.401\ e^{-(0.0354 \pm 0.0090)X} \quad \text{(for chair positioner)} \qquad (7)$$

and was not significantly different ($P>0.2$) from Equation 6. Both sets of human data are shown in Figure 10, the earlier values plotted as triangles and the more recent data plotted as open circles. Although the regression equation for humans which is shown in the figure (Eq. 6) is significantly different ($P<0.001$) from the equation for the relative counting rate of ^{42}K in the phantoms, there is little difference between the predicted values within the range of observed effective half-thicknesses of actual human adults and children which we have studied ($\sim$ 6 to 13 cm, see Figures 8, 9, and 10).

One additional calibration measurement in vivo at 2.75 MeV was obtained when a subject, 170 cm tall, weighing 78 kg (half-thickness = 10.7 cm) was given 1 μCi ^{24}Na orally in connection with another study. His total-body spectrum was recorded each hour for 7 hours following intake. All excreta were collected and were assayed for their ^{24}Na content. Counting rates per retained μCi (corrected for radioactive decay) relative to that in polyethylene phantom #3 (Table 2) increased from about 0.928 to 0.978 over the course of the day.

Table 4. Adults in earlier ^{42}K calibration study (chair positioner).

Subject	Sex	Weight, kg	Height, cm	Half-thickness cm	[cpm/μCi in person / cpm/μCi in phantom]
TE	F	45.4	163	8.3	1.045
DT	M	53.6	184	8.5	1.047
RM	F	59.1	168	9.4	0.982
RL	M	65.9	170	9.8	0.990
AR	F	65.9	160	10.2	0.971
CM	M	77.3	178	10.4	1.003
PW	M	82.3	184	10.6	0.987
DB	F	78.2	161	11.0	0.902
DA	M	92.7	174	11.5	0.907
BC	M	102.3	187	11.7	0.968

Counting rates of ^{214}Bi at 1.76 MeV and bremsstrahlung radiation from ^{90}Sr + ^{90}Y in a 55 kg female who acquired a body burden of ^{226}Ra and ^{90}Sr as a dial painter were compared to ^{226}Ra and ^{90}Sr standards in polyethylene phantom #3 (Table 2). Her calculated body content was similar to corresponding values measured in 8 other laboratories in the U.S. and Europe (Lloyd et al., 1976a).

Sources in polyethylene phantoms. The counting rate of an individual radioactive source within each of the series of phantoms (Table 2) is affected by two opposing factors: with increasing radius, the amount of overlying absorbing material increases, thus decreasing the relative counting rate, but at the same time, the center of radioactivity within the phantom is lifted closer to the detectors, thus increasing the relative counting rate. The magnitude of the first of these two effects depends upon the photon energy, but the second (geometry) should be energy-independent and, therefore, uniform for all emitters. The theoretical relationship between geometry and self absorption for single and multiple crystal human counters has been treated by Andrasi and Kotel (1975), Genna (1966), Joyet (1968), Joyet and Baudraz (1968), Marinelli (1966), and Naversten (1966).

Counting rates in various energy bands were determined for each radioactive source in each of the phantoms. For the various emitters, the counting rate in the primary photopeak of interest decreased as an exponential function of phantom radius. Counting rates in energy bands below the primary photopeak (mainly Compton scatter) remained fairly constant for a given emitter in all phantoms. Typical extreme values were in the order of ± 5%. Because phantom #3 is the one that is used to contain the standards for comparative counting of humans and has a half-thickness similar to the mean for humans ≈ 10.3 cm,

counting rates for sources within each phantom were divided by the counting rate in phantom #3. All sources used in this part of the study were in 10 ml or 5 ml glass ampoules, except the ^{40}K standard and one of the ^{42}K standards, which were both in identical Lucite cylinders, such as the one described previously for the 430 gK. In the case of the ^{42}K source, the cylinder was filled with aged distilled water in which the ^{42}K was dissolved.

For a given emitter centered in the phantoms, the relative counting rate in the primary photopeak was fitted by the method of least squares to the equation:

$$R = a\, e^{-kx} \qquad (8)$$

where: R = counting rate relative to that for phantom #3

a and k = coefficient and exponential constant unique to each emitter

e = base of natural logarithms

x = minor radius of phantom, in cm

It was found that the calculated value of both parameters "a" and "k" depended upon photon energy in a regular way, that is, tended to decrease with increasing photon energy (Table 5 and Fig. 11). The exponential constants (k) for ^{208}Tl and ^{24}Na were not significantly different from zero ($P>0.2$). This suggests that the opposing effects of geometry and self-absorption were about equal for the 2.62 and 2.75 MeV gamma-rays, but that for gamma-rays of lower energy, the effects of self-absorption were greater than geometry effects. Corresponding values of the parameters "a" and "k" can be determined for emitters other than those given in Table 3 from the relationships proposed in Fig. 11. It appears that a satisfactory calibration for humans can be approximated by

Table 5. Parameters determined for the dependence of relative counting rate upon phantom radius for various emitters in the primary photopeak.

Nuclide	Gamma-ray Energy, MeV	Coefficient a	± S.D.	Exponential Constant k	± S.D.	P, Significance Level of k,
^{210}Pb	0.047	1.942	±0.027	0.0644	± 0.00118	<0.001
^{241}Am	0.060	1.844	±0.063	0.0594	± 0.00272	<0.001
^{51}Cr	0.32	1.510	±0.051	0.0400	± 0.00072	<0.001
^{85}Sr	0.514	1.391	±0.010	0.0320	± 0.00056	<0.001
^{137}Cs	0.662	1.307	±0.026	0.0260	± 0.00140	<0.001
^{54}Mn	0.835	1.275	±0.017	0.0236	± 0.00132	<0.001
^{65}Zn	1.12	1.210	±0.011	0.01866	± 0.00074	<0.001
^{40}K	1.46	1.091	±0.011	0.00840	± 0.00112	<0.01
^{42}K*	1.53	1.117	±0.008	0.01072	± 0.00058	<0.001
^{214}Bi	1.76	1.039	±0.007	0.00370	± 0.00058	<0.001
^{208}Tl	2.62	1.000	±0.010	-0.00029	± 0.00058	>0.2
^{24}Na	2.75	1.006	±0.013	-0.00027	± 0.00102	>0.2

* 10 ml ampoule source. The ^{42}K cylinder source counted about 1.04 times higher.

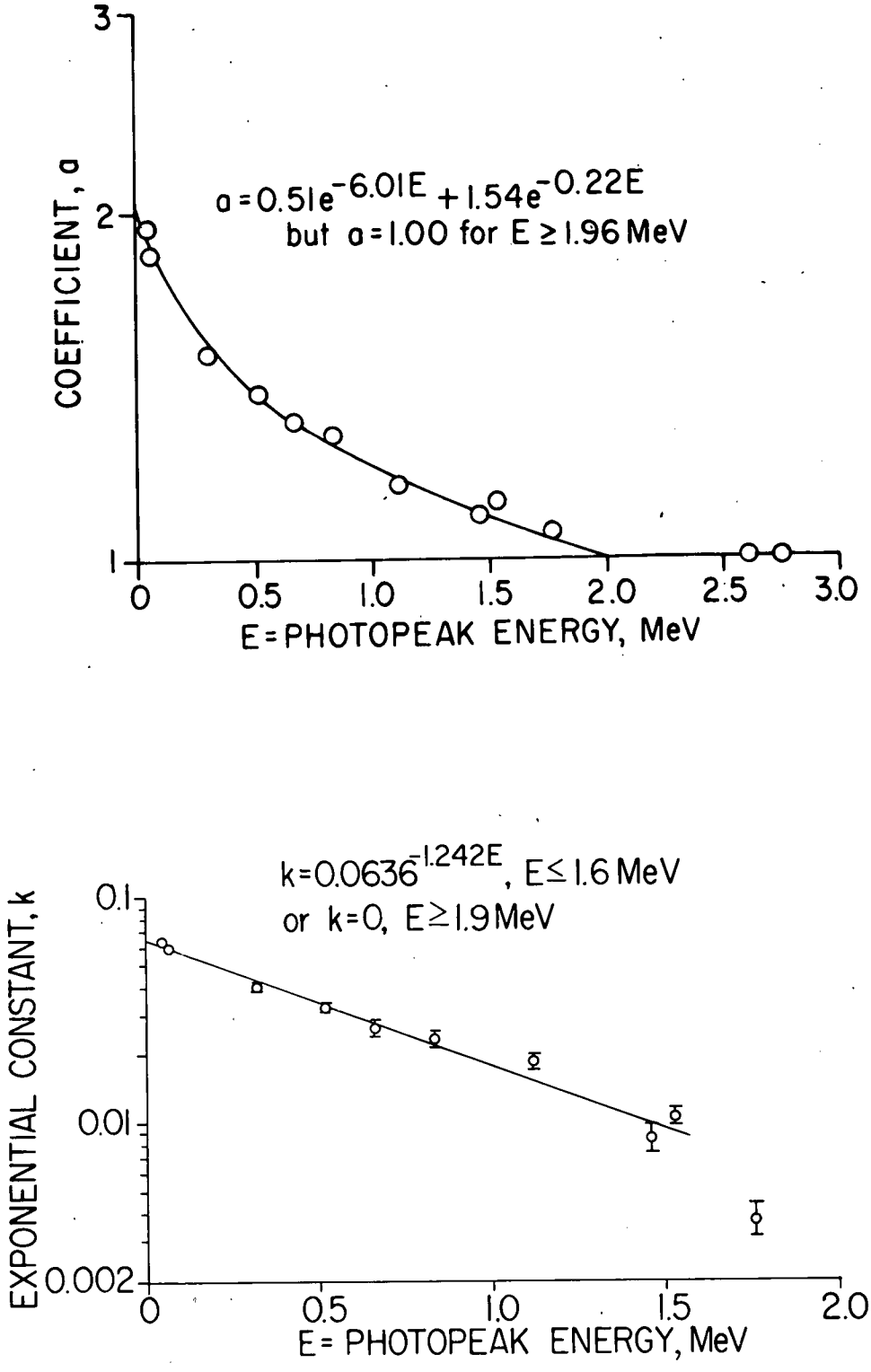

Figure 11A,B. Empirically-determined values of the coefficient, "a" (top), and exponential constant "k" (bottom), as a function of photon energy (see Table 5).

data obtained from studies in the phantoms for emitters other than ^{83}Rb, ^{137}Cs, ^{42}K, and ^{24}Na, for which a primary calibration was done.

In an attempt to separate the effects of geometry and self-absorption which are combined in the measurements made of various gamma-ray emitters within the polyethylene phantoms (Table 5), a second series of 6 phantoms was constructed entirely of styrofoam (density $\simeq$ 0.027 g/cm^3), identical in size to those shown in Table 2, but corresponding masses were in the order of 35 times less than their respective counterparts. Six gamma-ray emitters of various energies from 0.047 MeV to 2.62 MeV (^{210}Pb, ^{241}Am, ^{137}Cs, ^{65}Zn, ^{214}Bi, ^{208}Tl) were run in all of these comparatively massless phantoms, and the dependence of relative counting rate upon phantom thickness was determined (Table 6). Within the range of phantom radii used, the effect of geometry alone could be expressed either as (A) an inverse square relationship with respect to the distance from the source to a representative point in the detector system, or (B) an exponential function of phantom thickness of the form $R' = f\, e^{+gx}$. The exponential equation was chosen for convenience, and the constants (f) and (g) were found to be similar for all tested emitters (Table 6). There were no statistically significant differences among the resulting equations, and no dependence of either the individual parameters (f) and (g) upon photon energy could be shown ($P>0.2$). These data indicate that the differential effects of photon self-absorption within the phantoms were minor. Therefore, results from all 6 emitters were combined, and this yielded the following equation which describes the counting rate (R') relative to styrofoam phantom #3 as a function of phantom radius (x):

$$R' = 0.658e^{+\,(0.0408\,\pm\,0.0008)x} \qquad (9)$$

Table 6. Effects of geometry upon relative counting rate for various emitters counted in the series of styrofoam phantoms. In all cases, the dependence of relative counting rate (R) upon phantom radius (x) was fitted to a single exponential function of the form $R = f\ e^{+gx}$.

Emitter	Gamma-ray Energy, MeV	f ± S.D.	g ± S.D.
^{210}Pb	0.047	0.6837 ± 0.0151	0.03872 ± 0.00370
^{241}Am	0.060	0.6523 ± 0.0182	0.04194 ± 0.00468
^{137}Cs	0.662	0.6586 ± 0.0192	0.04010 ± 0.00490
^{65}Zn	1.12	0.6431 ± 0.0136	0.04210 ± 0.00356
^{214}Bi	1.76	0.6383 ± 0.0149	0.04230 ± 0.00394
^{208}Tl	2.62	0.6738 ± 0.0104	0.03946 ± 0.00262
All	0.047 to 2.62	0.658 ± 0.007	0.0408 ± 0.0008

Dividing equation 8 (Table 5 data) by equation 9 gives equation 10 for the counting rate (relative to that in phantom #3) of a source fixed in position at 10 cm above the positioner, and surrounded by a phantom of radius (x) with linear attenuation coefficient ($\mu \simeq k - g$)

$$\frac{R}{R'} = \frac{a\ e^{-kx}}{f\ e^{+gx}} = \left(\frac{a}{f}\right) e^{-(k-g)x} = \left(\frac{a}{f}\right) e^{-\mu x} \qquad (10)$$

where μ = overall linear attenuation coefficient for the lucite + polyethylene combination.

As a rough check, values for μ given on page 714 of Evans (1955) for water at corresponding energies were compared with our calculated values, and it was found that, except for the lowest energy emitters, there was approximate agreement (Table 7) in support of the reasonability of our calibration. It was not surprising that our values devived for μ for ^{210}Pb, ^{241}Am, and ^{51}Cr were lower (by about 50%) than those given by Evans (1955), since the photoelectric absorption for polyethylene (CH_2) is lower than that for water (H_2O), and scattered photons from primary beams of low energy can still appear in the photopeak for NaI(Tl) spectroscopy. For example, in a Compton event, the 0.32 MeV gamma-ray of ^{51}Cr scattered through 30^o is degraded to only 0.30 MeV (equation 1.6, page 675 of Evans, 1955), and would be included in the photopeak integrated between 0.28 and 0.36 MeV. In contrast, an identical 30^o Compton process degrades the 0.66 MeV photon of ^{137}Cs to 0.56 MeV, which is not included in the photopeak summed between 0.62 and 0.70 MeV.

At very low energies, such as for ^{210}Pb, ^{241}Am, etc., most of the detected gamma-rays are those which originate from the shallow layers of the subject's front surface, since radiation coming from deeper layers is strongly attenuated. Therefore, the counting rate per μCi in the person should be considerably greater

Table 7. Linear attenuation coefficients in polyethylene phantoms (empirical) and water (theoretical).

Nuclide	Photon Energy, MeV	Empirical Values for Phantoms		Attenuation Constant for Water (μ in cm^{-1})*
		Coefficient (a/f)	Attenuation Constant (k-g)	
^{210}Pb	0.047	2.951	0.1052	0.22
^{241}Am	0.060	2.802	0.1002	0.20
^{51}Cr	0.320	2.295	0.0808	0.12
^{85}Sr	0.514	2.114	0.0728	0.10
^{137}Cs	0.662	1.986	0.0668	0.085
^{54}Mn	0.835	1.938	0.0644	0.080
^{65}Zn	1.12	1.839	0.0595	0.070
^{40}K	1.46	1.658	0.0492	0.060
^{42}K	1.53	1.698	0.0515	0.060
^{214}Bi	1.76	1.597	0.0445	0.050
^{208}Tl	2.62	1.520	0.0408†	0.042
^{24}Na	2.75	1.529	0.0408†	0.040

*Taken from Fig. 1.3, page 714, in Evans (1955).

†Using a slope of zero rather than the values in Table 5.

than the counting rate per μCi of an ampoule source centered in polyethylene phantom #3. Calibration by methods similar to the *in vivo* techniques described earlier for ^{83}Rb, ^{137}Cs, ^{42}K, and ^{24}Na or calibration with subjects of known body contents would be necessary for precision work at low energies.

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TWO NEW ANIMAL MODELS FOR ACTINIDE TOXICITY STUDIES

G. N. Taylor, P. A. Gardner, C. W. Jones,
R. D. Lloyd, and C. W. Mays

ABSTRACT: Two small rodent species, the grasshopper mouse (Onychomys leucogaster) and the deer mouse (Peromyscus maniculatus) have tenacious retention in the liver and skeleton of plutonium and americium. The retention following intraperitoneal injection of Pu and Am in citrate solution ranged from 20 to 47% (liver) and 19 to 42% (skeleton), relatively independent of post-injection times, varying from 30 to 125 days. Based on observations extended to 125 days post-injection, the biological half-times appeared to be long.

Both of these rodents are relatively long-lived (median lifespans of approximately 1400 days), breed well in captivity, and adapt suitably to laboratory conditions. It is suggested that these two species of mice, in which plutonium is partitioned between the skeleton and liver in a manner similar to that of man, may be useful animal models for actinide toxicity studies.

INTRODUCTION

Plutonium undergoing translocation via the vascular system is retained about equally in the liver and the skeleton of man (1-5), with effective half-times of approximately 40 years and 100 years, respectively (5). The ICRP currently lists the initial partitioning as 45% skeleton and 45% liver (5), which indicates that the average concentration in the 1.8-kg liver is greater than in the 10-kg skeleton of a reference man. Obviously, the most representative animal models for plutonium toxicity studies must likewise have relatively high and prolonged retention in the liver as well as the skeleton. Nevertheless, much of the data related to metabolic and toxicity patterns of actinide elements have been derived from common laboratory mice and rats, which have significant differences in comparison to man, especially with regard to the liver. For example, the retention half-time of plutonium in the hepatic tissue of these species is approximately 9 to 60 days (6-8). Retention of actinides is also brief in the chinchilla liver (9) and the rabbit liver (9-19). This rapid excretion of plutonium and other actinides from the liver restricts the scope of toxicity

investigations in these animals to the skeleton and precludes assessment of liver risk.

Although the effective half-time of plutonium in the hepatic tissue of most laboratory rats and mice is short, this is not true for all rodent species. For example, the effective half-time of americium in the livers of the Syrian and Chinese hamsters is approximately 1000 days (12). These species also retained 80% or more of the ^{252}Cf burden present at 8 days post-injection through a 128 day period, as compared to an approximate half-time of 5 days in the rat (13). This prolonged retention in the hamster liver more nearly parallels the retention pattern of plutonium in the human liver and provides a much more representative animal model with which to study actinide toxicity.

In spite of the advantages of relatively high and prolonged retention of plutonium and some of the other actinides in the liver, several factors have arisen that complicate the use of hamsters in long-term toxicity studies: (A) Significant life shortening related to kidney disease (14) plus a high incidence of liver cirrhosis (15) have been observed in the Syrian hamster. (B) In the Chinese hamster liver a 70% frequency of nodular hyperplasia (16) has been reported. This is a complicating factor since nodular hyperplasia has been a prominent radiation-induced end-point in actinide studies, at least in dogs (17), and a high incidence would significantly reduce the sensitivity of experiments designed to evaluate the toxicity of liver-seeking radionuclides. Because of these disease factors in the hamster, we have searched for other small rodent species which have high and prolonged retention of plutonium and other actinides in the liver, and are not afflicted with a high frequency of spontaneous diseases. It is the purpose of this report to indicate 2 animal models that may be useful for internal emitter studies.

METHODS

The mice were from outbred colonies and were adults at the time of injection. They were housed in a constant temperature room ($70\pm 4^{o}F$) on ground corn cob bedding in 7" x 11" x 5" plastic cages. Wayne Lab Blox and water were fed ad lib.

The radionuclides were administered in a citrate buffered solution via a single intraperitoneal injection. In the two animals injected with the

$^{237+239}Pu$ plus ^{241}Am mixture (mice OL 6-24 and PM 11-18), the photon emitter, ^{237}Pu, was added to the ^{239}Pu solution prior to the preparation of the citrate solution, to ensure that the ^{237}Pu would act as an isotopic tracer for the ^{239}Pu.

The radionuclide analysis was based on gamma-ray spectroscopy, using a pair of eight-inch diameter by four-inch thick NaI(Tl) crystals and monitoring of the 100 keV gamma-rays (^{237}Pu) and the 60 keV gamma-rays (^{241}Am).

RESULTS

Based on our preliminary investigations, two species that warrant further investigation are the grasshopper mouse (*Onychomys leucogaster*)(Fig. 1) and the deer mouse (*Peromyscus maniculatus*)(Fig. 2).

Americium and plutonium retention was high and based on post-injection times extending out to 69 days (*O. leucogaster*) or 125 days (*P. maniculatus*), the excretion rate appears to be low (Table 1). The partitioning between the liver and the skeleton was approximately equal in the deer mouse, but the liver retention exceeded the skeletal retention in the grasshopper mouse.

The median lifespan of *O. leucogaster* is reported to be approximately 1400 days and the maximum as approximately 2000 days (18). Lifespan data for *P. maniculatus* were not found. However, the median and maximum lifespans for a very close relative, *P. leucopus*, is given as 1476 days and 3040 days, respectively (19). The longevity of these species exceeds that of common laboratory mice (*Mus musculus*) significantly (19,20). These longer lifespans would have distinct advantages in some radionuclide toxicity studies.

Tentatively, the incidence of liver disease, although not zero, appears to be significantly lower than has been reported in hamsters (15,19). For example, in 282 autopsies involving *Peromyscus maniculatus* of unspecified ages, Cosgrove observed 4 tumors, only 1 of which was a liver tumor (21). In the closely related species, *Peromyscus leucopus*, a frequency of 12 and 4% hepatic tumors was observed in males and females, respectively (22). The mice were reared under laboratory conditions, and 65% of the animals were beyond 900 days age. The reported frequency was higher in *O. leucogaster* and in a series of autopsies involving old adults (over 900 days age), liver lesions were observed in 22% of the mice (18). These included both hyperplastic

Table 1. PERCENT OF INJECTED DOSE RETAINED FOLLOWING INTRAPERITONEAL INJECTION OF ^{241}Am OR $^{237+239}Pu$ IN GRASSHOPPER MICE (*Onychymus leucogaster*) AND DEER MICE (*Peromyscus maniculatus*).

MOUSE NO.	DAYS PI TO DEATH	INJECTED µCi	PERCENT OF INJECTED ACTIVITY RETAINED		
			LIVER	OTHER	TOTAL
GRASSHOPPER MICE					
213W1	31	0.0075 (Am-241)	45.3	22.7	68.0
213W2	69	0.0075 (Am-241)	46.9	22.8	69.7
OL6-24	46	0.0101 (Am-241)	35.9	25.2	61.1
OL6-24	46	0.0015 (Pu-237)*	42.8	35.0	77.8
DEER MICE					
214W4	30	0.0227 (Am-241)	24.4	24.9	49.3
213W3	47	0.0075 (Am-241)	20.0	20.3	40.3
214W5	61	0.0227 (Am-241)	30.9	22.8	53.7
214W2	92	0.0227 (Am-241)	26.6	32.0	58.6
214W3	125	0.0227 (Am-241)	37.9	21.0	58.9
PM11-18	46	0.0101 (Am-241)*	38.4	18.7	57.1
PM11-18	46	0.0015 (Pu-237)*	35.3	41.6	76.9

*Mice received 0.0041 µCi ^{239}Pu + 0.0015 µCi ^{237}Pu + 0.0101 µCi ^{241}Am.

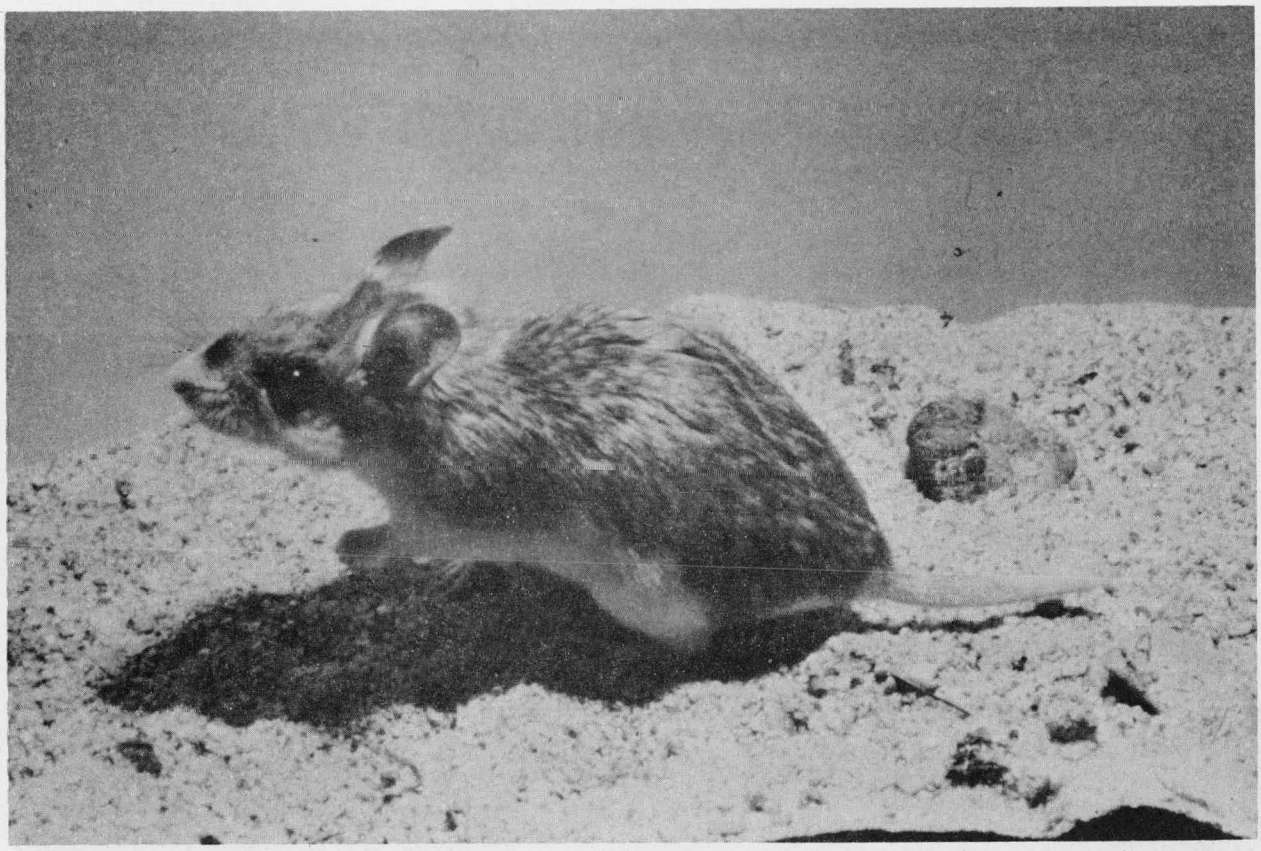

FIGURE 1. Adult grasshopper mouse (*Onychomys leucogaster*). X 1.

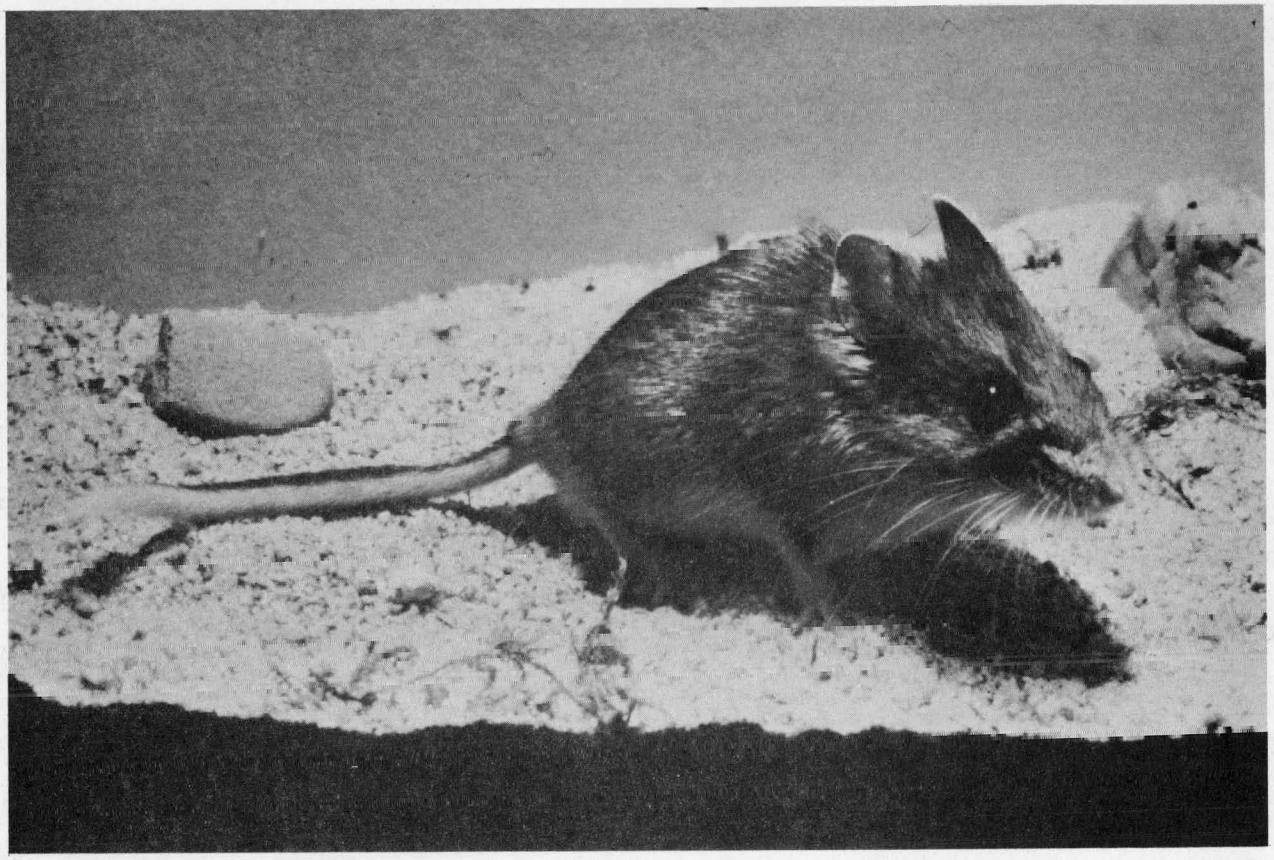

FIGURE 2. Adult deer mouse (*Peromyscus maniculatus*). X 1.

and neoplastic changes, including 3 malignancies. Although these data do not provide precise incidence values, they are suggestive that the frequency of spontaneous hepatic changes is appreciably smaller than that reported in the hamster.

The grasshopper mouse (*O. leucogaster*) and the deer mouse (*Peromyscus maniculatus*) adapt well to laboratory conditions and breed well in captivity (18,19). They are also relatively odorless. Our preliminary investigations indicate that both species may be useful animal models in toxicity studies involving actinides.

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SALICYLIC ACID FAILED TO INCREASE THE EFFICACY OF Ca-DTPA IN THE DECORPORATION OF PLUTONIUM AND AMERICIUM

C. W. Jones, R. D. Lloyd, and C. W. Mays

ABSTRACT: Male and female C57BL/Do mice were each given a single i.p. injection of $^{237+239}Pu$ + ^{241}Am as the citrate complex at 45 days of age. Twice weekly i.p. injections of either 500 µmol/kg Ca-DTPA or 500 µmol/kg Ca-DTPA, mixed just before injection with 2000 µmol/kg salicylic acid (SA), were begun 3 days after nuclide administration and continued for 5 weeks. Control mice were injected each time with isotonic saline. Nuclide retention was determined by in vivo counting using NaI(Tl) spectrometry. At the end of treatment, total-body retention of Pu or Am in the mice given Ca-DTPA was significantly lower ($P<0.001$) than in the control animals. Mice treated with Ca-DTPA + SA were statistically indistinguishable from mice treated with Ca-DTPA ($P>0.70$ for ^{237}Pu and $P>0.20$ for ^{241}Am).

INTRODUCTION

It has been claimed that essentially 100% of the Pu in the body, including that bound by bone, could be removed by a combination of Ca-DTPA and salicylic acid (SA).[1]

The experiment described herein was designed to duplicate the mixed ligand chelate therapy recently described by Schubert and Derr (1978), and to test the treatment efficacy for ^{241}Am removal.

METHODS

Male and female C57BL/Do mice, 45 days old and weighing an average 16.5 g, were injected intraperitoneally (i.p.) with a citrate solution containing ^{237}Pu(IV), ^{239}Pu(IV), and ^{241}Am(III). The photon-emitter ^{237}Pu was added to the ^{239}Pu before preparation of the citrate solution to ensure that the ^{237}Pu would act as an isotopic tracer for ^{239}Pu.

Three days after nuclide administration, three groups of male and female mice were injected i.p. twice weekly with either 500 µmol/kg Ca-DTPA, or 500 µmol/kg Ca-DTPA, mixed just before injection with 2000 µmol/kg SA, or a 0.9% solution of sodium chloride (control animals). The treatment regimen was followed for five weeks. Nuclide retention was periodically determined by *in vivo* counting using NaI(Tl) spectrometry.[2] On day 34, after nuclide injection, the mice were sacrificed by methoxyflurane inhalation.

RESULTS AND DISCUSSION

The average ^{237}Pu and ^{241}Am biological retention for each group of mice during the treatment period is shown in Figures 1 and 2. Group comparison "t" tests[3] showed that by day 34, after nuclide injection, the mice treated with Ca-DTPA plus SA had total-body retentions of ^{237}Pu and ^{241}Am which were not statistically different ($P>0.70$ for ^{237}Pu and $P>0.20$ for ^{241}Am) when compared to mice injected with Ca-DTPA. Total-body retention of ^{237}Pu and ^{241}Am in the Ca-DTPA treatment group on day 34 was significantly less ($P<0.001$ for ^{237}Pu and $P<0.001$ for ^{241}Am) than the control animals.

Contrary to a report by Schubert and Derr,[1] which claimed that virtually 100% of injected ^{239}Pu citrate was decorporated, this study shows that the plutonium decorporation efficacy of Ca-DTPA is not enhanced by the addition of salicylic acid. The decorporation efficacy for americium is also not enhanced by Ca-DTPA plus salicylic acid therapy. It is noted that Schubert has recently retracted the published results of Schubert and Derr.[4]

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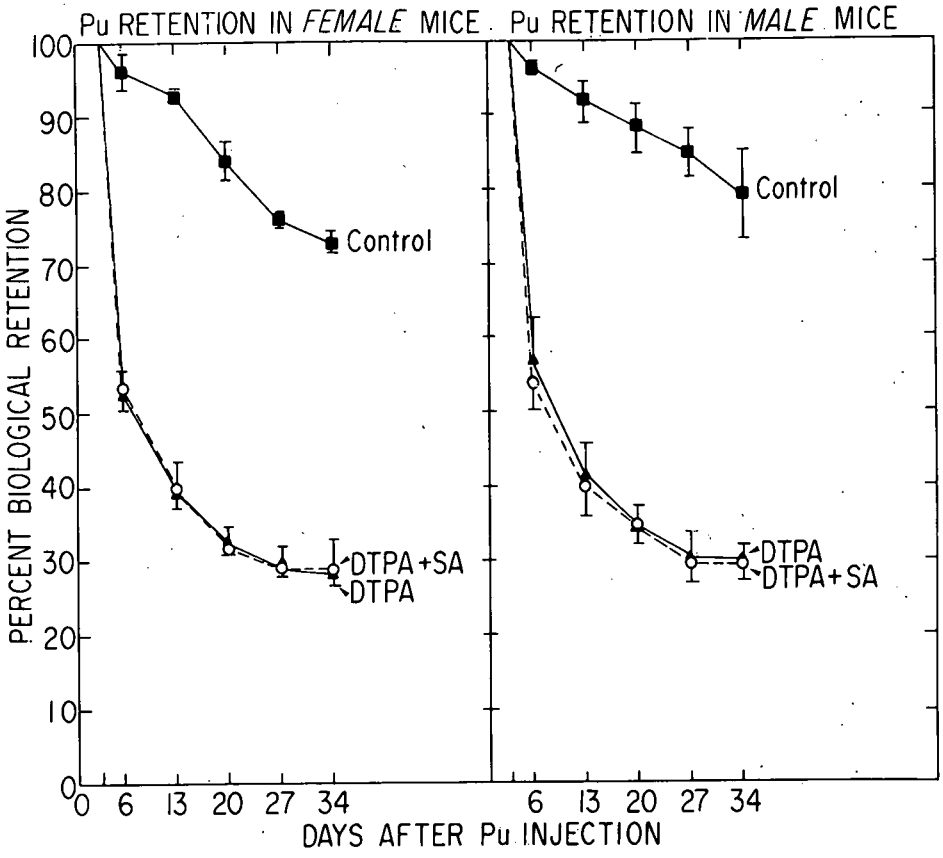

FIGURE 1. Biological retention of plutonium in female and male C57BL/Do mice as measured by total-body counting during treatment. The plotted points represent mean values (n = 4 for each group of females and n = 3 for each group of male mice), and the error bars represent standard errors of the mean. Biological retention equals effective retention corrected for radioactive decay.

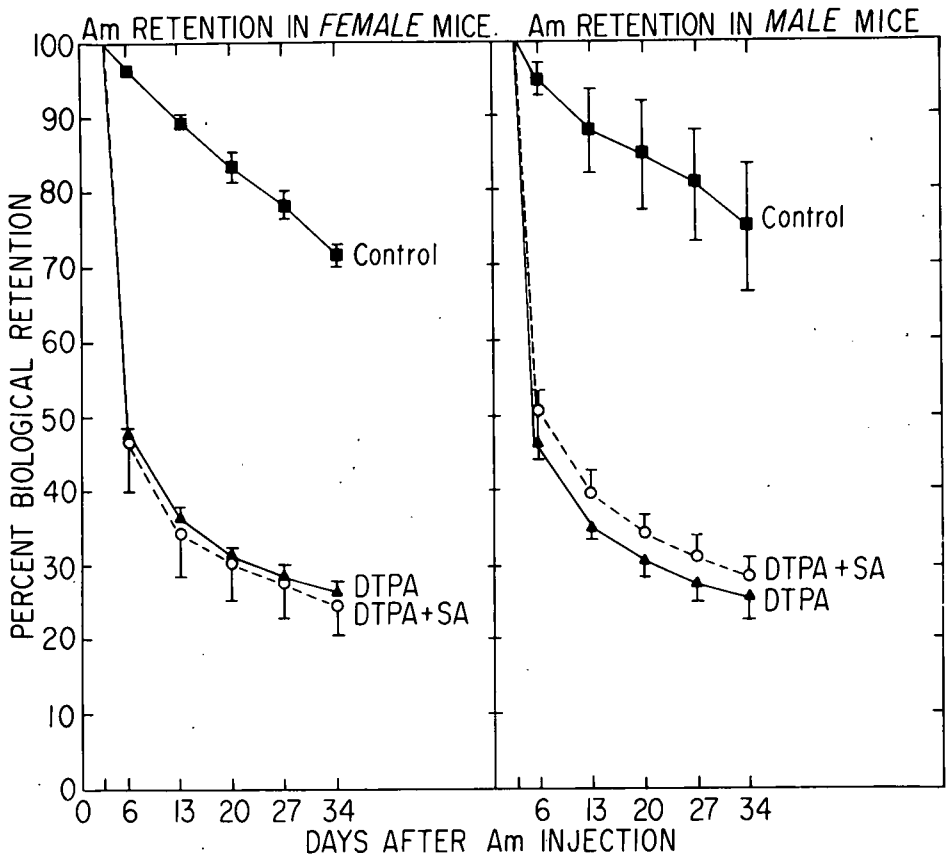

FIGURE 2. Biological retention of americium in female and male C57BL/Do mice as measured by total-body counting during treatment. The plotted points represent mean values (n = 4 for each group of females and n = 3 for each group of male mice), and the error bars represent standard errors of the mean. Biological retention equals effective retention corrected for radioactive decay.

FAILURE TO DETECT SYNERGISM OF SALICYLIC ACID AND DTPA IN DECORPORATION OF Pu OR Am*

R. D. Lloyd, C. W. Jones, C. W. Mays, D. R. Atherton, F. W. Bruenger, and G. N. Taylor

It has been suggested (Nature 275: 311, 1978) that nearly 100% of body Pu might be removed by repeated injections of a mixture of DTPA and salicylic acid (SA). To test this possibility, 3 adult male beagles were each given a single i.v. injection of $^{237+239}Pu$ + ^{241}Am as the citrate complex. Daily i.v. injections of 30 μmol Zn-DTPA + 120 mol SA per kg, mixed together just before injection, were begun 3, 7 or 14 days later and continued for an additional 4 weeks. Pu + Am in dogs, excreta, and tissues was determined by NaI(Tl) spectrometry. At the end of treatment, total-body retention in the animals given the first SA + DTPA injection at 3, 7 or 14 days was, for Pu 53%, 47%, and 57%, respectively, and, for Am, was 45%, 41%, and 53%, respectively. Excretion of both Pu and Am was no greater than that of comparable beagles given DTPA alone. Female C57BL/Do mice, about 50 days old, were injected i.p. with the same Pu + Am mixture given the dogs. Three days later, treatments of two groups were begun with i.p. injections of 500 μmol Ca-DTPA/kg or 500 μmol Ca-DTPA + 2000 μmol SA/kg, and were continued twice weekly for about 1 month. Untreated control mice retained substantially more Pu and Am than the other 2 groups, but the retention in those animals given SA + DTPA was indistinguishable from that of mice given DTPA alone.

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THE EFFECTIVENESS OF MIXED LIGAND CHELATION FOR THE REMOVAL OF PLUTONIUM AND AMERICIUM IN THE HAMSTER

F. W. Bruenger, W. Stevens, D. R. Atherton, R. R. Greenlee, C. W. Mays, C. W. Jones and R. D. Lloyd

ABSTRACT: DTPA and the combination of DTPA plus salicylic acid or other benzene derivatives which are ortho-di-substituted with functional groups containing one or more oxygen and/or nitrogen atoms as electron donors, were tested for their ability to remove ^{239}Pu and/or ^{241}Am from hamsters. Mixed ligand chelation of these actinides by combination of DTPA and any one of these compounds did not result in an increased efficacy for the removal of actinides, as has been reported elsewhere.

A recent report described new concepts in the decorporation of Pu and Cd (1). After injecting mice with Pu, a twice weekly treatment was initiated three days later with a mixture of DTPA or EDTA together with a bidentate agent such as salicylic acid (SA). It was reported that the liver was cleared with four treatments and the skeletal Pu was reduced to undetectable levels with ten treatments in this experiment. In as much as the complete removal of Pu had been reported after a few treatments, the application of mixed ligand chelation offered an exciting improvement over earlier decorporation therapy. However, since mice lose Pu relatively easily these experiments were repeated in this laboratory using Syrian hamsters which are known to bind Pu and Am tenaciously and to retain these nuclides with halftimes which are closer to those expected in humans.

METHODS

Twenty Syrian hamsters weighing 100-115 g were injected intraperitoneally with 0.45 µCi ^{241}Am/kg. Americium was chosen instead of Pu because of the ease of detection of its 60 keV γ-emission and because its retention and removal characteristics in hamsters are known and similar to those of Pu. Three days later, animals were separated into five groups of 4 hamsters each and their whole body content of ^{241}Am was determined by γ-ray spectroscopy. The retentions at this time were taken as 100%. After this initial count,

treatment was initiated by intraperitoneal injections of the chelants according to the following schedule:

Group:	a.	No treatment	(control)
	b.	Ca-DTPA	500 µmol/kg
	c.	Ca-DTPA + SA	500 µmol/kg and 2000 µmol/kg
	d.	Zn-DTPA	500 µmol/kg
	e.	Zn-DTPA + SA	500 µmol/kg and 2000 µmol/kg

The addition of 4 times the concentration of SA to the primary chelant increased the osmolarity of the injection solution to values which were considerably higher than physiological.

This treatment was given twice weekly for 4 weeks and animals were counted after each week of treatment just before a new injection was made. After 4 weeks, a final count was made and the animals were sacrificed. At autopsy, the liver was removed and the residual body and liver were counted separately. Since soft tissue organs other than the liver retain very little of the nuclide, the counting rate of the residual body was taken as a measure of the skeletal retention. Final retention was expressed as:

a. retention in treated animal/retention in untreated control
b. retention in animals treated by mixed ligand therapy/retention in animals given Ca-DTPA only.

In a further experiment, a variety of other potential bidentate chelons were tested in combination with DTPA using the same regimen as above but with Chinese hamsters. The following agents were tested for their ability to remove Pu and Am:

a. anthranilic acid
b. o-hydroxyphenylacetic acid
c. tiron
d. catechol
e. p-aminosalicylic acid
f. salicyl-hydroxamic acid
g. phthalic acid
h. rhodotorulic acid

In addition to the hamster experiments, partition coefficients in an H_2O (0.1 N NaCl)/hexane system for Pu-DTPA and Pu-[DTPA + SA] were determined. A variety of other ortho-disubstituted bidentate ring compounds which, in combination with DTPA,could possibly form mixed ligand chelates, were also tested. The partition of Pu-DTPA was evaluated at three different pH's: at 4.82 (1:1 complex), at 7.43 (2:3 complex) and at 9.01 (1:2 complex). All others were determined at pH 7.5. The bidentate chelon was added to preformed Pu-DTPA and then mixed into the aqueous phase. Partitions were expressed as:

$$\frac{\text{Pu in aqueous phase}}{\text{Pu in organic phase}}$$

RESULTS

Sequential whole body counting of the hamsters during the treatment period gave no indication of an enhanced decorporation brought about by mixed ligand treatment (SA) when compared to DTPA. Results of the various treatments obtained at time of autopsy are expressed in Table 1a and b. Figures in Table 1a represent average retentions. These are normalized so that the average retention before treatment was 100%. For convenience, those in Table 1b have been normalized to terminal whole body, skeleton or liver retention in the controls being equal to one.

The combination of none of the compounds listed above under a to h with Ca-DTPA increased the removal of Pu or Am from bone. DTPA in combination with tiron, rhodotorulic acid or phthalic acid enhanced the loss of both nuclides from the liver without any obvious toxic effects. Salicylhydroxamic acid resulted in accelerated loss of the two nuclides from the liver but the administration of this agent or catechol caused prolonged coma or convulsions, respectively, and this precludes their usefulness.

The partition of Pu between the aqueous and organic phase did not change drastically with either the pH of the aqueous phase or with the bidentate compound that was used to form a mixed ligand chelate. In all cases Pu was present as a strongly hydrophilic entity, regardless of the structure of the chelate (or mixed ligand chelate) that was formed.

The ratio $Pu_{(aq)}/Pu_{(org)}$ for three different hydronium ion concentrations

and the combination of DTPA and salicylic acid is shown in Table 2. Partition coefficients for Pu-DTPA and for the combination of DTPA with any of the oligodentates tested were very similar. None of the chelates exhibited any significant organophilicity.

SUMMARY

The drastic increase in the decorporation of Pu from mice as reported in Nature could not be repeated using Syrian hamsters as the test animal and Pu or Am as the nuclide to be removed. A statement regarding the lipophilicity of the Pu-DTPA complex also could not be verified. No reason for the large difference in the results obtained can be given at this time, but our data cast serious doubts on the validity of those published in Nature. Therefore, caution rather than extreme optimism is in order until the differences can be resolved.

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ACKNOWLEDGEMENT

We thank Dr. Curtis L. Atkin for suggesting the use of rhodotorulic acid in our chelation studies and for furnishing our supply of this material.

TABLE 1

TERMINAL RETENTION OF Am IN SYRIAN HAMSTERS AFTER TREATMENT WITH DTPA OF [DTPA + SA*]

	Whole Body	Skeleton (Non-Liver)	Liver
a. Retention of Am in Treated Hamsters/Retention in Untreated Control			
Control	1.	1.	1.
Ca-DTPA	0.256 ± .016	0.492 ± .038	0.032 ± .031
Ca-DTPA + SA*	0.246 ± .032	0.413 ± .015	0.073 ± .069
Zn-DTPA	0.282 ± .035	0.484 ± .031	0.071 ± .077
Zn-DTPA + SA*	0.307 ± .038	0.452 ± .028	0.157 ± .062
b. Retention of Am in Treated Hamsters/Retention in Animals Treated with Ca-DTPA only			
Ca-DTPA	1.	1.	1.
Ca-DTPA + SA*	0.925 ± .120	0.840 ± .030	2.26 ± 2.14
Zn-DTPA	1.057 ± .022	0.984 ± .062	2.21 ± 0.80
Zn-DTPA + SA*	1.155 ± .144	0.918 ± .056	4.83 ± 2.52

TABLE 2

		$\frac{Pu_{(aq)}}{Pu_{(org)}}$
Pu-DTPA : 1:1	(pH 4.82)	34,000
Pu-DTPA : 2:3	(pH 7.43)	27,000
Pu-DTPA : 1:2	(pH 9.01)	26,000
Pu-DTPA + SA*	(pH 7.4)	40,000

* Salicylic Acid

THE EXAMINATION OF SOME CHELATING AGENTS TO DECORPORATE FIXED BODY-BURDENS OF CADMIUM

C. W. Jones, R. D. Lloyd, and C. W. Mays

ABSTRACT: Male and female C57BL/Do mice, five to six months old, were injected intraperitoneally with 2.0 mg/kg cadmium citrate labeled with about 2.0 μCi ^{109}Cd per mouse. Three days after cadmium injection, male mice were injected subcutaneously with 2,3 dimercaptopropanesulfonate (DMPS), and female mice were injected subcutaneously with calcium disodium ethylenediaminetetraacetate (CaEDTA), salicylic acid (SA), or 2,3 dimercaptopropanesulfonate, alone, or in combination. A total of four treatment injections were administered to each group of mice. Cadmium total-body retention was measured by in vivo counting using NaI(Tl) spectrometry. Male mice given DMPS, and groups of females given EDTA, SA, EDTA + DMPS, EDTA + SA, or EDTA + DMPS + SA had total-body retentions of cadmium no different from saline controls ($P>0.05$). Measurement of cadmium content in kidneys, livers, gonads, and femora excised from test animals also showed no difference from corresponding organs in control animals ($P>0.10$).

INTRODUCTION

Cadmium was recognized many years ago as a highly toxic element. The uses for cadmium have increased so that it is now widely encountered industrially and environmentally. At present, there is no truly effective treatment for poisoning by this metal.

An excellent and detailed review of the uptake, distribution, and toxicity of cadmium has been published.[1] Unlike many elements which reach constant concentrations in tissue, the concentration of cadmium continues to increase with age. This indicates firm binding in tissue with a long biological half-life estimated at 10 to 30 years in humans.[1] Therefore, it appears that a chelating agent capable of removing a fixed body-burden of cadmium would be most desirable.

In this study, mice were injected with cadmium labeled with ^{109}Cd and treated with several chelating agents, alone, or in various combinations, to

determine if an effective method of cadmium removal could be achieved in this manner. An attempt was also made to extend the achievements claimed by Schubert and Derr, 1978.[2]

METHODS

Male and female C57BL/Do mice, five to six months old, and 25 g average body weight, were injected intraperitoneally (i.p.) with 2.0 mg/kg cadmium citrate labeled with approximately 2.0 μCi ^{109}Cd per mouse. Three days after cadmium injection, male mice were injected subcutaneously (s.c.) with one of three dosages (Table 1) of 2,3 dimercaptopropanesulfonate (DMPS), and female mice were injected s.c. with calcium disodium ethylenediaminetetraacetate (CaEDTA), salicylic acid (SA), or 2, 3 dimercaptopropanesulfonate (DMPS), alone, or in combination (Table 1). Control animals were injected s.c. with a 0.9% solution of sodium chloride. The treatment injections were given daily for four days. Cadmium total-body retention was measured shortly before and during treatment by counting the 88 keV gamma-ray emitted from ^{109}Cd, using dual 20 x 10 cm NaI(Tl) detectors.[3] Four days after the start of chelation treatment, the mice were sacrificed by methoxyflurane inhalation. The liver, kidneys, gonads, and femora were excised and put in separate 3-dram glass vials with 95% ethanol as preservative. The ^{109}Cd activity in each sample was determined by gamma-ray spectroscopy in a well-type scintillation crystal.[4]

RESULTS AND DISCUSSION

Retention of Cadmium in Male Mice Treated with DMPS.

Table 2 exhibits results of this part of the study. Group comparison (t) tests[5] showed that four treatment injections of DMPS, started 3 days after cadmium injection, at 1 or 4 mmole/kg/day, did not reduce significantly ($0.05<P<0.80$) the total-body cadmium burden in test animals from controls. All the mice receiving 16 mmole/kg/day of DMPS died within 24 hours after the initial injection of DMPS. Cadmium content of the liver, kidneys, gonads, and femora, excised from treated animals, was not significantly different ($0.10<P<0.80$) from corresponding organs in control animals.

Table 1. CHELATING AGENTS USED IN MALE OR FEMALE C57BL/Do MICE.

Chelating Agent	Dosage (mmole/kg/day)
MALES*	
Saline Control	1.2
DMPS	1.0
DMPS	4.0
DMPS	16.1
FEMALES*	
Saline Control	1.2
CaEDTA	0.1
SA	1.0
CaEDTA + DMPS	0.1 + 1.0
CaEDTA + SA	0.1 + 1.0
CaEDTA + DMPS + SA	0.1 + 1.0 + 1.0

*Four mice per group.

In general, this study showed that a fixed body-burden of cadmium will not be decorporated by DMPS. However, Jones, *et al.*, reported[6] that DMPS given orally is at least as effective as $Na_2CaEDTA$, and will assure the survival of mice suffering from accute cadmium poisoning when administered within 3.5 hrs after cadmium injection.

Retention of Cadmium in Female Mice.

Table 3 exhibits the total-body cadmium content of female mice injected with CaEDTA, SA, or DMPS, alone, or in combination. In all cases, the chelating agents failed to decorporate cadmium significantly ($0.05<P<0.80$) when compared to the control animals. Cadmium content of the liver, kidneys, gonads, and femora excised from test animals showed no significant difference ($0.10<P<0.975$) from comparable organs in the controls.

Our results indicate that neither DMPS nor any of the other tested agents, when used alone or in combination, is effective at decorporating fixed burdens of cadmium. It is noted that Schubert[7] has retracted the results of Schubert and Derr.[2]

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Table 2. BIOLOGICAL RETENTION OF CADMIUM IN MALE C57BL/Do MICE AS MEASURED BY TOTAL-BODY COUNTING DURING CHELATION TREATMENT. STABLE CADMIUM WITH ^{109}Cd WAS INJECTED 3 DAYS PRIOR TO THE START OF TREATMENT. RETENTION IS NORMALIZED TO THE START OF CHELATION TREATMENT.

	PERCENT BIOLOGICAL RETENTION		
GROUP	Day 0	Day 2	Day 4
Saline Control	100	96.73 ± 0.57	96.10 ± 1.63
DMPS 1 mmole/kg/day	100	97.06 ± 1.22	95.84 ± 1.71
DMPS 4 mmole/kg/day	100	94.19 ± 1.60	93.09 ± 1.73
DMPS 16 mmole/kg/day	100	Dead	

Table 3. BIOLOGICAL RETENTION OF CADMIUM IN FEMALE C57BL/Do MICE AS MEASURED BY TOTAL-BODY COUNTING DURING CHELATION TREATMENT. STABLE CADMIUM WITH ^{109}Cd WAS INJECTED 3 DAYS PRIOR TO THE START OF TREATMENT. RETENTION IS NORMALIZED TO THE START OF CHELATION TREATMENT.

	PERCENT BIOLOGICAL RETENTION		
GROUP	Day 0	Day 2	Day 4
Saline Controls	100	98.76 ± 2.47	97.20 ± 1.02
CaEDTA	100	98.20 ± 1.02	97.41 ± 0.93
SA	100	96.46 ± 1.47	95.87 ± 1.35
CaEDTA + DMPS	100	97.25 ± 2.03	95.14 ± 1.39
CaEDTA + SA	100	97.71 ± 1.34	97.10 ± 0.95
CaEDTA + DMPS + SA	100	97.32 ± 1.88	94.75 ± 2.49

DECORPORATION OF Pu OR Am IN BEAGLES BY 3,4,3-LICAMS

R. D. Lloyd, F. W. Bruenger, D. R. Atherton, C. W. Jones, F. L. Weitl,* P. W. Durbin,* K. N. Raymond,* G. N. Taylor, W. Stevens, and C. W. Mays

ABSTRACT: The compound, 3,4,3-LICAMS = N^1, N^5,N^{10},N^{14}-tetra(2,3-dihydroxy-5-sulfobenzoyl)-tetraazatetradecane, tetrasodium salt, has been tested as a decorporation agent in beagles given $^{237+239}Pu$ + ^{241}Am citrate 30 minutes prior to its administration. Compared to untreated beagles or those given Ca-DTPA alone, the concentration of Pu in blood plasma was reduced significantly in dogs given LICAMS. The Am concentration in plasma was not reduced by LICAMS. Instead, the rate of Am disappearance from plasma was slowed substantially. Total-body retention of Am was reduced from control values only slightly by LICAMS, but markedly by DTPA. In contrast, Pu retention was diminished by LICAMS to a greater extent than by DTPA. The effects of combined LICAMS and DTPA treatment were not additive. It appears that 3,4,3-LICAMS is an effective chelating agent for Pu, but an indication of neophrotoxic effects in 2 dogs given 30 μmol LICAMS/kg indicates that the toxicity of the catecholates must be investigated thoroughly.

INTRODUCTION

Scientists at the Lawrence Berkeley Laboratory, University of California, synthesized a series of chelons designed to be specific for the decorporation of PuIV (Weitl and Raymond, In Press). Their design was based on the fact that PuIV and FeIII have similar chemical properties with respect to their coordination chemistry. Both, to some extent, are bound to the same endogenous ligands (transferrin, ferritin) in biological systems. The chelons were modeled structurally to resemble some naturally occurring (microbially produced) iron chelators. The result of this effort was the synthesis of various linear catechoylamide sulfonate (LICAMS) compounds. The most promising of these, as determined in preliminary tests (Durbin, *et al.*, In Press) of PuIV decorporation in mice, 3,4,3-LICAMS = N^1,N^5,N^{10},N^{14}-tetra (2,3-dihydroxy-5-sulfobenzoyl)-tetraazatetradecane, hydrated tetrasodium salt (MW

*Lawrence Berkeley Laboratory, University of California.

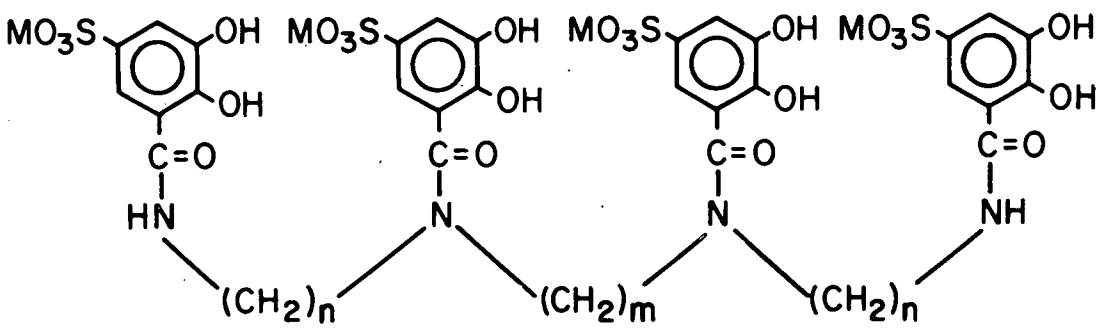

FIGURE 1. 3,4,3-LICAMS : n = 3, m = 4.

approximately 1200; see Fig. 1), in the following called LICAMS, was tested in beagles.

METHODS

Six young adult male beagles, 615 to 695 days of age, were each given a single intravenous injection of 0.233 μCi ^{239}Pu + 0.087 μCi ^{237}Pu + 0.575 μCi ^{241}Am in citrate buffer solution of pH 3.5. Thirty minutes later, the animals were given an intravenous injection of 30 μmole Ca-DTPA/kg or 30 μmol LICAMS/kg or (30 μmol Ca-DTPA + 30 μmol LICAMS)/kg, as shown in Table 1. The osmolarity of the DTPA solution was 247 mOs/kg, and that of the LICAMS (including 0.154 M NaCl) was 435 mOs/kg. The combined treatment with DTPA and LICAMS was administered by separate injections of DTPA followed 0.5 minutes later by LICAMS.

The concentrations of Pu and Am in the plasma of the 6 beagles were measured during the first day after injection. Two blood samples were drawn from each beagle before administration of the decorporation agents and another four were taken 1, 2, 3, and 24 hours after nuclide injection. Total alpha-disintegrations (^{239}Pu + ^{241}Am) were determined by liquid scintillation counting in Instagel^{R} and ^{239}Pu was measured by the method of Keough and Powers (1970). Americium was then calculated by subtracting the Pu from the sum of the Am and Pu alpha-disintegrations.

All excreta produced between radionuclide injection and sacrifice were collected and analyzed for their Pu and Am content by NaI(Tl) spectrometry. Retention of Pu and Am in the total-body and in the liver was determined *in vivo* at 7 days after injection, just prior to sacrifice by a combination of total-body and partial-body counting (Lloyd, *et al.*, 1975a, 1976a). Measurement of ^{237}Pu and ^{241}Am in excised livers was made by photon counting shortly after death was induced by exsanguination under pentothal anesthesia.

RESULTS

The average concentrations of the two nuclides in plasma resulting from the various treatments are shown in Fig. 2 for Am and Pu. Each of the three treatment groups is compared with previously determined data from untreated dogs injected with Am or Pu. The disappearance of Am from plasma was not

Table 1. MALE BEAGLES USED IN THE STUDY

DOG	Age at Injection (Days)	Weight at Injection (kg)	Treatment at 30 Minutes*
2403 (T226P1.7W)	625	8.65	Ca-DTPA
2406 (T227P1.7W)	615	8.05	Ca-DTPA
2404 (T228P1.7W)	625	8.45	LICAMS
2407 (T229P1.7W)	615	9.30	LICAMS
2384 (T230P1.7W)	695	9.95	Ca-DTPA + LICAMS
2416 (T231P1.7W)	591	7.75	Ca-DTPA + LICAMS

*30 μmol/kg of each agent.

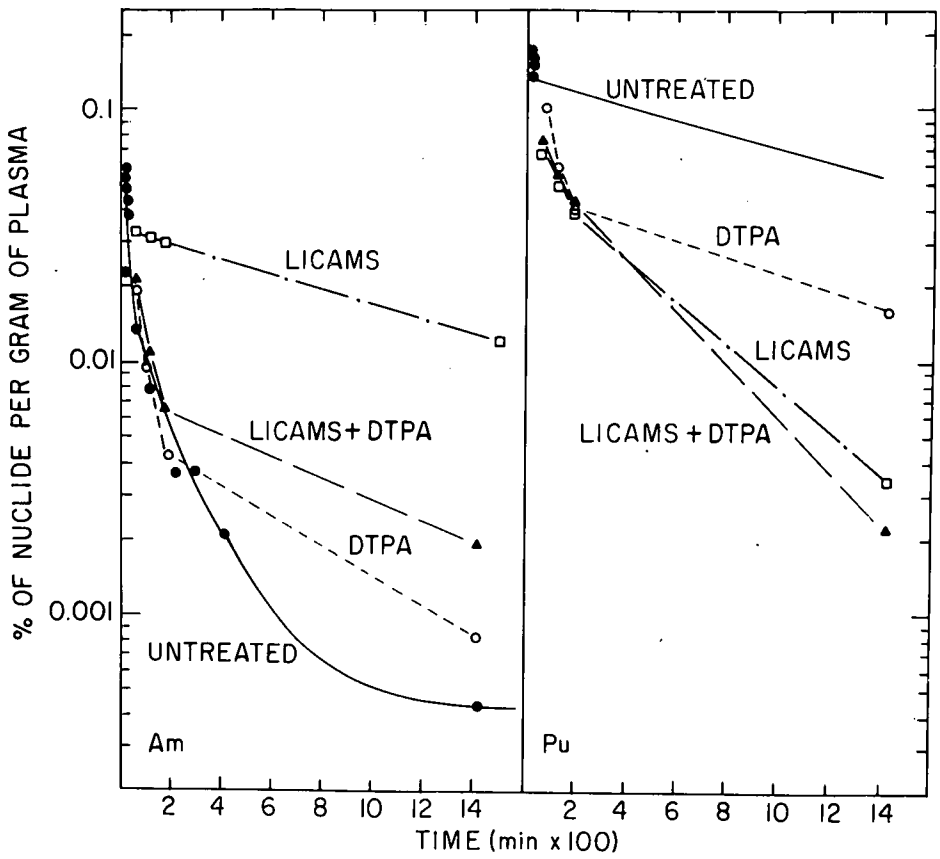

FIGURE 2. Concentration of ^{241}Am (left) and $^{237+239}Pu$ (right) in blood plasma of beagles as a function of time after radionuclide injection as influenced by treatment with DTPA alone or LICAMS alone, or DTPA + LICAMS at 30 minutes. Values for untreated animals were from 6 young adult beagles given ^{241}Am and not treated (D.R. Atherton, unpublished) and Stover, *et al.* (1977), for ^{239}Pu.

enhanced by treatment with either of the agents or their combination. In the plasma of dogs which received the LICAMS only, the concentration of Am at 1 day after injection was more than an order of magnitude higher than that seen in the untreated dogs or in those given DTPA. The concentration of Pu in plasma was considerably lower in the two groups which received the LICAMS, while the group receiving DTPA alone occupied a position between the untreated group and the LICAMS group. However, the effect of the combined treatment with DTPA and LICAMS was not additive.

Retention of both Pu and Am, as indicated by excreta subtraction, was diminished by each of the 3 treatments, as compared to other beagles given Am or Pu injections but not treated (Fig. 3). Ca-DTPA alone was more effective for removing Am from the body than LICAMS alone, but retention in dogs given the combination of LICAMS and Ca-DTPA was not lower than that of dogs given Ca-DTPA alone. In contrast, LICAMS alone was more effective in removing Pu than Ca-DTPA alone, and retention in dogs given the combination of LICAMS and Ca-DTPA was not substantially lower than that of dogs given LICAMS alone. Whereas DTPA was a much more effective decorporating agent for americium than for plutonium, LICAMS was substantially better for plutonium than for americium. Urinary excretion of Am and Pu accounted for about 90% of the total for all three groups, a value similar to that for Am in untreated beagles (Lloyd, *et al.*, 1975b), but different from the 30% value reported for Pu in untreated beagles (Lloyd, *et al.*, 1976b).

Plutonium and americium retention and partitioning between liver and non-liver (mainly skeleton) at 7 days following treatment are shown in Table 2. Values for the groups given DTPA and DTPA + LICAMS were similar for Am, and results for groups given LICAMS and LICAMS + DTPA were similar for Pu. There was no indication that the effects of these 2 agents might be additive for the removal of either element. Roughly half of the retained Am was found in each of the 2 compartments, whereas 0.4 of the residual Pu was in the liver (0.33 to 0.46), and the non-liver tissue contained 0.6 of the total (0.43 to 0.67). Although the non-liver tissue in the 2 dogs given LICAMS alone represented the lowest proportionate plutonium retention (0.54) of any group, differences between the 2 groups given LICAMS and the dogs given DTPA alone were not significant ($P > 0.3$) according to the group comparison ("t") test (Woolf, 1968).

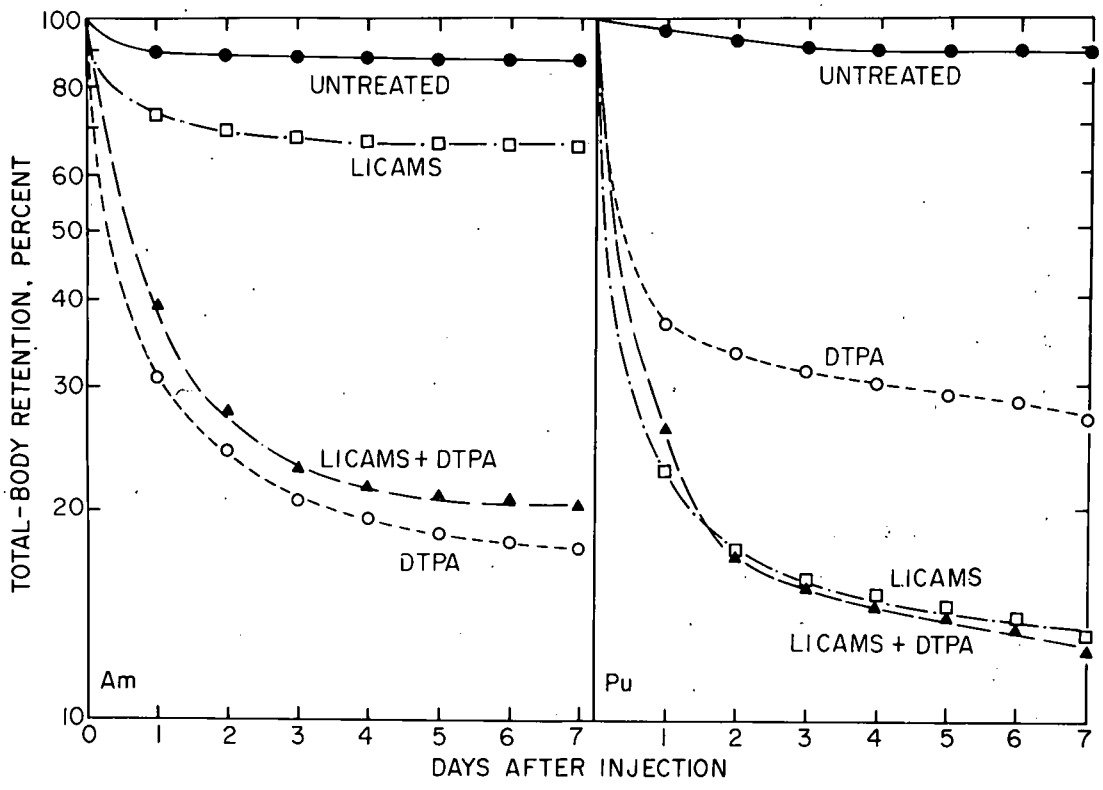

FIGURE 3. Total-body retention of injected ^{241}Am (left) and $^{237+239}Pu$ (right), determined from excreta assay, as influenced by treatment with DTPA alone or LICAMS alone or DTPA + LICAMS. Each of the curves marked with the name of the administered agent represents the average for the 2 dogs in the group. The curves marked "untreated" represent the mean values of 5 young adult beagles injected with ^{241}Am and not treated for 7 days (Lloyd, *et al.*, 1975b) and 14 young adult beagles injected with ^{239}Pu(IV) citrate and given no decorporation treatments (see Fig. 1 of Lloyd, *et al.*, 1976b).

Therefore, these data do not establish any substantial difference in partitioning between liver and non-liver tissue when compared to dogs given DTPA or to beagles not given DTPA or LICAMS.

During the period from injection to sacrifice, the blood urea nitrogen in two beagles treated with LICAMS (dogs 2407 and 2416) increased from 15 to 33 and from 16 to 50 mg/100 ml, respectively. In addition, dog 2407 exhibited focal renal hemorrhages and dog 2416 suffered from a marked kidney edema.

DISCUSSION

It appears from this limited experiment that 3,4,3-LICAMS is an effective chelating agent for PuIV. Administration of the chelon removed PuIV from the circulation and prevented its deposition in liver and skeleton by excretion to a greater extent than DTPA. Neither LICAMS nor DTPA seems to have altered substantially the partitioning of retained activity between liver and skeleton. The agent LICAMS has a greater affinity for PuIV than for AmIII, a finding that was expected from the small size of the charge cavity that was incorporated into the 3,4,3-LICAMS molecule (ionic radii of PuIV and AmIII are 9×10^{-3} μm and 9.9×10^{-3} μm, respectively).

A longer residence time of Am in the circulation of LICAMS-treated dogs may be explained by a lower excretion rate of Am-LICAMS vs. Am-DTPA by the kidney. Some rerouting of circulating Am-LICAMS to the urine does occur, however, as indicated by a somewhat reduced total-body and liver retention following LICAMS treatment (Fig. 3). No conclusion as to the removal of Pu or Am already deposited in liver or skeleton from exposure much earlier than 30 minutes before treatment can be drawn from this experiment.

The tetracatecholates show considerable promise as agents for decorporation of ions of high charge and small size. However, the as yet undetermined degree of nephrotoxicity observed in two of the dogs given this amount of LICAMS (which would be equivalent to 2.5 g in a 70 kg human) should receive further study. In general, these findings of enhanced removal of Pu from the circulation and reduced deposition in body tissues by LICAMS are very promising. The relationship between removal efficiacy and toxicity of 3,4,3-LICAMS and similar agents should be investigated in detail and the compounds redesigned, if necessary.

Table 2. AMERICIUM AND PLUTONIUM RETENTION IN BEAGLES 7 DAYS AFTER DECORPORATION THERAPY VIA i.v. INJECTION OF DTPA ALONE, LICAMS ALONE, OR DTPA + LICAMS. EACH VALUE FOR TREATED DOGS REPRESENTS THE MEAN OF 2 ANIMALS. RETENTION OF ^{241}Am AND $^{237+239}Pu$ IN LIVER, IN NON-LIVER TISSUE AND IN THE TOTAL-BODY WAS DETERMINED BY *IN VIVO* COUNTING, AND HEPATIC RETENTION IN THE TREATED DOGS WAS CONFIRMED BY COUNTING OF EXCISED LIVERS. VALUES FOR UNTREATED ANIMALS WERE TAKEN FROM LLOYD, *ET AL.* (1975b) FOR ^{241}Am AND FROM STOVER, *ET AL.* (1968, 1971, AND 1972) FOR ^{239}Pu.

	^{241}Am					
	Percent Retention in			Proportionate Retention		
Treatment	Total-Body	Liver	Non-Liver	Total-Body	Liver	Non-Liver
Untreated	87.3	42.2	45.1	1.0	0.48	0.52
LICAMS	67.2	35.6	31.6	1.0	0.53	0.47
DTPA	20.1	9.5	10.6	1.0	0.47	0.53
DTPA + LICAMS	20.9	11.0	9.9	1.0	0.53	0.47
Mean					0.50	0.50

	$^{237+239}Pu$					
	Percent Retention in			Proportionate Retention		
Treatment	Total-Body	Liver	Non-Liver	Total-Body	Liver	Non-Liver
Untreated	90	35	55	1.0	0.39	0.61
DTPA	29.7	9.9	19.8	1.0	0.33	0.67
LICAMS	13.7	6.3	7.4	1.0	0.46	0.54
DTPA + LICAMS	11.6	4.9	6.7	1.0	0.42	0.58
Mean					0.40	0.60

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APPENDIX: TABULAR DATA ON THE EXPERIMENTAL DOGS (31 MARCH 1979)

Tables I and II list the toxicity and test animals, respectively. Toxicity animals are those animals which are usually maintained until sacrifice becomes a clinical necessity; test animals may be sacrificed as needed for special studies.

Dogs are put into the toxicity study at graded injection levels. At each level, about half the dogs are male and half female. Litter mates are used whenever possible. Each animal receives the designated dose of one radionuclide in a single intravenous injection at approximately 17 months of age. At this age the skeleton is mature with all epiphyses fused except those of the ribs.

The five injection levels designated by integers are those specified at the early meetings of the consultants, and those designated by nonintegers have been added by the laboratory staff. Since those injection levels were originally specified in "retained" activities, the actual injections are four times the desired "retained" μCi/kg for ^{90}Sr, ^{210}Pb, ^{224}Ra, ^{226}Ra, and ^{228}Ra, and 1.11 times the desired "retained" μCi/kg for ^{228}Th, ^{239}Pu, ^{241}Am, $^{243/244}Cm$, $^{249+252}Cf$, and ^{253}Es.* The desired "retained" activities are the same for all

---

*Since radioactive decay and excretion occur continuously, the term "total body retention" is obviously meaningless unless the time after injection is specified. Our present measurements indicate that the effective retention of alkaline earth elements decrease to about 25% of that injected by the following times after injection:

Element	Time (days)
^{90}Sr	134
^{210}Pb	98
^{224}Ra	5
^{226}Ra	271
^{228}Ra	214

Retention of actinide elements decreases to about 90% at post-injection times shown below:

^{228}Th	6
^{239}Pu	6
^{241}Am	6
$^{243/244}Cm$	1
$^{249/252}Cf$	1
^{253}Es	1

the radionuclides except ^{90}Sr, in which case they are greater by a factor of 10. Injection level 1 is the basis of the scheme, and is 10 times the maximum permissible concentration of ^{226}Ra in man. Level 1 = 10 x $\frac{0.1\ \mu Ci\ ^{226}Ra}{70\ kg\ man}$ = 0.0143 "retained" μCi/kg. All other injection levels are simple multiples of level 1, as shown below.

Level 0.1	is	1/27	of level 1
Level 0.2	is	1/9	of level 1
Level 0.5	is	1/3	of level 1
Level 0.7	is	2/3	of level 1
Level 1.5	is	2	times level 1
Level 1.7	is	3	times level 1
Level 2	is	6	times level 1
Level 3	is	18	times level 1
Level 4	is	54	times level 1
Level 4.5	is	94	times level 1
Level 5	is	162	times level 1

The numbering system for the dogs has been built around the injection program and serves as a code to describe each dog's place in the experiment. The first letter tells the sex of toxicity animals (M = male, F = female). When the first letter is T, the dog is a test animal. M, F, or T is followed by a number which denotes chronological order of groups in the case of toxicity dogs and of individual test dogs.

Next comes a code letter for the radionuclide: R = ^{226}Ra, P = ^{239}Pu, M = ^{228}Ra, T = ^{228}Th, S = ^{90}Sr, J = ^{85}Sr, Q = ^{224}Ra, W = ^{241}Am, L = ^{210}Pb, G = ^{249}Cf, F = ^{252}Cf, C = $^{243/244}Cm$, E = ^{253}Es, K = ^{237}Pu, U = ^{233}U, V = ^{238}U, and A = Ancillary.

"A" following the regular dog number means that the dog is a replacement, "H" following the regular dog number means that the dog received its dose in more than one injection. "B," "C," or "D" denotes an intended special assignment, but most of these dogs have been redesignated for lifespan toxicity studies. "E" in the final position is used to denote that the dog listed is a St. Bernard. "P" in the final position indicates that the nuclide was injected in particulate form. "Y" in the final position indicates that the animal was injected as a juvenile. "N" in the final position indicates that the animal was injected as a neonate. A plus (+) in the final position denotes that the animal was "old" when injected. Letters denoting a radionuclide may follow the final number, in which case the letter indicates that two radionuclides were given. The injection level refers to the radionuclide appearing first in the identifying code.

Example: M1R5 is a male animal in the first radium group at the highest injection level.

Although M1R5, M1R4, M1R3, M1R2, M1R1, and M1R0 constitute a group and were injected at the same time, the tables are arranged according to injection level to facilitate comparison of all the R5 animals, all the R4 animals, etc.

The conditions listed in the injection tables under "Comments on Dead Dogs" present the cancers and the lesions or factors that had the most prominent effect on the clinical status of the animal. For example, multiple rib fractures, which seldom produced symptoms, are not listed, even though their incidence was usually much higher than the crippling fractures involving the limb bones or mandible. The hematological changes have been omitted unless they were extreme. Increased rate of tooth loss, hepatic changes, eye lesions, and many other factors in the various syndromes have not been included because of space limitations. Over the years many soft tissue tumors have been removed surgically. In many instances, the conditions that have been listed were the reasons for sacrifice of the animal but they were not the immediate cause of death. Most of the animals were euthanized when death appeared imminent or when life could no longer be prolonged humanely.

DOSIMETRY

The tables include the calculated average dose in rads to the skeleton at death. ^{90}Sr, ^{226}Ra, ^{228}Ra, ^{241}Am, ^{249}Cf, and ^{252}Cf doses are calculated for each dog using its individually observed retention values: ^{239}Pu, ^{228}Th, and ^{224}Ra doses are based on our average skeletal retention equations. For our standard beagle, the following equations were used for the EFFECTIVE* skeletal retention at (t) days after injection:

*Effective retention is decreased both by radioactive decay and biological elimination.

$^{226}Ra = 0.412e^{-0.558t} + 0.105e^{-0.0730t} + 0.196e^{-0.00488t} + 0.287e^{-0.000299t}$
(5-level only)

$^{226}Ra = 0.251e^{-0.982t} + 0.211e^{-0.269t} + 0.210e^{-0.0155t} + 0.177e^{-0.00204t} + 0.151e^{-0.000150t}$
(lower levels)

$^{222}Rn/^{226}Ra = 0.075\ (1-e^{-0.181t})\ t^{0.158}$
(All levels)

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^{239}Pu (dose level 5) $= 0.07e^{-0.0011t} + 0.43$

^{239}Pu (dose level 4) $= 0.11e^{-0.0011t} + 0.39$

^{239}Pu (dose level 3) $= 0.15e^{-0.0011t} + 0.34$

^{239}Pu (lower levels) $= 0.29e^{-0.0011t} + 0.21$

$^{228}Ra = 0.251e^{-0.982t} + 0.211e^{-0.269t} + 0.21e^{-0.0158t} + 0.177e^{-0.00237t} + 0.151e^{-0.000479t}$
(pure at t = 0)

84% retention of *in vivo* produced ^{228}Th and daughters.

$^{228}Th = 0.69e^{-0.00113t}$

$^{224}Ra/^{228}Th = 0.895$

$^{212}Pb/^{228}Th = 0.866$

$^{90}Sr = 0.36e^{-0.95t} + 0.29e^{-0.12t} + 0.10e^{-0.0092t} + 0.12e^{-0.0020t} + 0.13e^{-0.00022t}$

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^{241}Am (dose level 5) $= 0.359 + 0.157\ (1-e^{-0.0065t})$

^{241}Am (dose level 4) $= 0.359 + 0.141\ (1-e^{-0.0029t})$

^{241}Am (dose level 3) $= 0.359 + 0.076\ (1-e^{-0.0021t})$

^{241}Am (lower levels) $= 0.359 + 0.015\ (1-e^{-0.0014t})$

$^{249}Cf = 0.498e^{-0.0000794t}$

$^{252}Cf = 0.498e^{-0.000791t}$

$^{224}Ra = 0.528\ e^{-0.214t} - 0.228\ e^{-9.01t}$

with the effective retention of ^{224}Ra daughters of:

^{220}Rn and $^{216}Po = 0.486\ e^{-0.214t} - 0.276\ e^{-4.65t}$

$^{212}Pb = 0.447\ e^{-0.214t} - 0.336\ e^{-2.40t}$

$^{212}Bi = {}^{212}Po + {}^{208}Tl = 0.391\ e^{-0.214t} - 0.350\ e^{-2.38t}$

Detailed retention data and dosimetric analysis have been presented in a special report, COO-119-241 (March 1970), supplemented by other reports in COO-119-252 (March 1977) and COO-119-253 (March 1978).

The skeletal doses in this report are based upon a wet skeleton which is 7.5% of the body weight at the time of injection (COO-119-246, pp. 167-192, 1972).

^{228}Ra doses deserve special comment. The dose from "pure" ^{228}Ra and its *in vivo* produced daughters is based on our best evaluation of 5.77 ± 0.02 yr for the ^{228}Ra half-period. The tabulated total doses include the contributions from ^{228}Th contamination in the injection solutions. For example, ^{228}Th contaminations of 0.6%, 3%, and 15%, respectively, account for 2.7%, 13%, and 42% of the total dose in rads at 1000 days. If injected ^{228}Th is 4 times more toxic rad-for-rad than is *in vivo* produced ^{228}Th, these injected ^{228}Th contaminations would account for 10%, 37%, and 74% of the total biological damage at 1000 days. Therefore, it may be desirable to use only results from the slightly contaminated (0.6% ^{228}Th) dogs in evaluation of ^{228}Ra toxicity.

TABLE I. CHRONIC TOXICITY ANIMALS (31 MAR. 1979)

A. RADIUM - 226

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
MO01RO.O	558	8.03		20 4 53		3116	
MO02RO.O	487	14.6		16 11 53		3675	
FO03RO.O	601	11.4		10 3 54		2139	
MO04RO.O	461	11.0		7 4 54		5284	
MO05RO.O	460	6.57		22 6 54		4018	
FO06RO.O	483	8.43		27 7 54		3182	
MO07RO.O	511	11.0		24 8 54		3360	
FO08RO.O	638	8.21		21 12 54		3361	
FO09RO.O	700	11.7		11 4 55		1550	
MO10RO.O	522	10.9		27 7 55		4698	
FO11RO.O	544	10.2		20 12 55		4575	
FO12RO.O	501	8.68		17 1 56		4283	
MO13RO.O	515	12.3		4 3 64		4752	
FO14RO.O	536	10.8		23 10 64	5272		
MO15RO.O	564	12.8		4 2 65		4372	
FO16RO.O	469	10.0		7 4 65		3677	
MO17RO.O	469	12.50		27 4 66	4721		
FO18RO.O	497	12.00		25 5 66	4693		
FO19RO.O	533	8.42		13 10 66	4552		
MO20RO.O	536	9.70		29 12 66	4475		
FO21RO.O	549	9.90		26 1 67		4234	
MO22RO.O	533	12.1		22 3 67		3907	
FO31RO.OB	536	10.6		23 10 64		4458	
FO31RO.OC	536	9.88		23 10 64		4690	
FO31RO.OD	542	9.9		21 9 65		4889	
FO32RO.OB	542	7.8		21 9 65		4657	
FO32RO.OC	532	11.7		21 9 65		4845	
FO32RO.OD	532	9.7		21 9 65		4734	
FO33RO.OB	532	9.8		21 9 65		3670	
FO33RO.OC	496	9.50		25 5 66		4509	
FO33RO.OD	496	11.80		25 5 66		3916	
FO34RO.OB	525	8.20		26 1 67	4447		
FO34RO.OC	520	8.9		22 3 67	4392		
FO34RO.OD	484	9.9		22 3 67		3185	
FO35RO.OB	502	9.41		1 2 68	4076		
FO35RO.OC	502	9.38		1 2 68	4076		
FO35RO.OD	552	8.86		9 1 69	3733		
FO36RO.OB	467	10.1		2 7 68	3924		
FO36RO.OC	467	9.17		2 7 68	3924		
FO36RO.OD	467	9.08		2 7 68	3924		
FO37RO.OB	801	11.1		20 5 69	3602		
FO37RO.OC	501	10.4		23 9 70		2788	
FO37RO.OD	501	10.9		23 9 70	3111		

A. RADIUM - 226

DOG NUMBER	COMMENTS ON DEAD DOGS
M001RO.O	SEMINOMA, LYMPHOSARCOMA
M002RO.O	TRANSITIONAL CELL CARCINOMA
F003RO.O	STATUS EPILEPTICUS
M004RO.O	CHRONIC INTERSTITIAL NEPHRITIS; THROMBOSIS
M005RO.O	OBTURATING PULMONARY EMBOLISM
F006RO.O	STATUS EPILEPTICUS
M007RO.O	STATUS EPILEPTICUS, NEPHRITIS
F008RO.O	PANCREATIC ADENOCARCINOMA
F009RO.O	AORTIC BODY TUMOR
M010RO.O	NEPHRITIS
F011RO.O	VAGINAL FIBROMA
F012RO.O	UNDETERMINED (NO BONE TUMOR)
M013RO.O	MALIGNANT MELANOMA (ORAL)
F014RO.O	
M015RO.O	CHRONIC PANCREATITIS; HYDROCEPHALUS
F016RO.O	EPIDERMOID CARCINOMA,LUNG CARCINOMA
M017RO.O	
F018RO.O	
F019RO.O	
M020RO.O	
F021RO.O	MAMMARY CARCINOMA
M022RO.O	SEPTICEMIA
F031RO.OB	STATUS EPILEPTICUS
F031RO.OC	BILIARY CALCULUS; VAGINAL LEIOMYOSARCOMA
F031RO.OD	CHRONIC PANCREATITIS
F032RO.OB	VALVULAR INSUFFICIENCY; CHRONIC PANCREATITIS
F032RO.OC	MAMMARY CARCINOMA
F032RO.OD	TRANSITIONAL CELL CARCINOMA
F033RO.OB	MAMMARY CARCINOMA
F033RO.OC	MELANOMA (ORAL)
F033RO.OD	MAMMARY CARCINOMA
F034RO.OB	
F034RO.OC	
F034RO.OD	HEMANGIOSARCOMA (SOFT TISSUE)
F035RO.OB	
F035RO.OC	
F035RO.OD	
F036RO.OB	
F036RO.OC	
F036RO.OD	
F037RO.OB	
F037RO.OC	PNEUMONIA
F037RO.OD	

A. RADIUM - 226

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
FO38RO.OB	501	11.5		23	9	70	3111		
FO42RO.OB	338	8.00		25	4	69		33	
M101RO.OY	92	4.65		1	4	75	1460		
M102RO.OY	88	3.60		25	3	75	1467		
M103RO.OY	93	4.38		24	4	75	1437		
F104RO.OY	89	4.53		14	3	75	1478		
F105RO.OY	88	4.51		25	3	75	1467		
F106RO.OY	92	3.64		1	4	75	1460		
M107RO.OY	93	4.32		8	3	77	753		
F108RO.OY	93	4.22		16	3	77	745		
F109RO.OY	88	2.92		19	1	78	436		
MO13RO.2	529	9.77	0.00577	4	3	64		4518	23
FO14RO.2	460	8.10	0.00836	23	10	64		3448	52
MO15RO.2	504	10.8	0.00873	4	2	65		4102	36
FO16RO.2	486	8.90	0.00665	7	4	65		4190	32
MO17RO.2	494	11.80	0.00711	27	4	66	4721		
FO18RO.2	497	9.30	0.00652	25	5	66		3387	21
FO19RO.2	533	10.6	0.00785	13	10	66		3611	36
MO20RO.2	546	11.4	0.00676	29	12	66		3493	25
FO21RO.2	549	11.5	0.00687	26	1	67		3101	21
MO22RO.2	533	12.9	0.00961	22	3	67	4392		
MO13RO.5	529	11.0	0.0171	4	3	64		3676	57
FO14RO.5	510	9.75	0.0220	23	10	64		5079	102
MO15RO.5	490	10.4	0.0263	4	2	65		4297	96
FO16RO.5	500	11.4	0.0205	7	4	65		4141	97
MO17RO.5	494	9.20	0.0215	27	4	66		4052	85
FO18RO.5	496	9.10	0.0197	25	5	66	4693		
FO19RO.5	533	10.0	0.0230	13	10	66	4552		
MO20RO.5	536	13.2	0.0206	29	12	66	4475		
FO21RO.5	538	8.80	0.0208	26	1	67		4281	78
MO22RO.5	520	12.3	0.0290	22	3	67		3192	89
MO31RO.5B	508	11.40	0.021	27	4	66		4310	103
FO31RO.5C	537	9.40	0.0235	22	12	65		4393	113
FO31RO.5D	537	11.70	0.0238	22	12	65		4797	108
MO32RO.5B	496	13.40	0.0196	25	5	66		3219	60
FO32RO.5C	519	10.10	0.0239	22	12	65		4180	102
FO32RO.5D	509	10.10	0.024	22	12	65		3870	104
MO33RO.5B	497	12.90	0.0194	25	5	66		3848	103
FO33RO.5C	527	10.60	0.0212	27	4	66	4721		

A. RADIUM - 226

DOG NUMBER	COMMENTS ON DEAD DOGS
FO38RO.OB	
FO42RO.OB	SPECIAL STUDY
M101RO.OY	
M102RO.OY	
M103RO.OY	
F104RO.OY	
F105RO.OY	
F106RO.OY	
M107RO.OY	
F108RO.OY	
F109RO.OY	
MO13RO.2	MALIGNANT MELANOMA (ORAL)
FO14RO.2	MALIGNANT MELANOMA (ORAL)
MO15RO.2	CIRCULATORY FAILURE
FO16RO.2	LYMPHOSARCOMA
MO17RO.2	
FO18RO.2	LUNG CARCINOMA
FO19RO.2	PNEUMONIA
MO20RO.2	UNDIFFERENTIATED MALIGNANCY (SOFT TISSUE)
FO21RO.2	MAMMARY CARCINOMA
MO22RO.2	
MO13RO.5	BILE DUCT CARCINOMA
FO14RO.5	FIBROSARCOMA (MANDIBLE)
MO15RO.5	MELANOMA (ORAL)
FO16RO.5	MAMMARY CARCINOMA; UTERINE CARCINOMA
MO17RO.5	ORAL MELANOMA
FO18RO.5	
FO19RO.5	
MO20RO.5	
FO21RO.5	HYPOTHALMIC HEMORRHAGE; GASTRIC ULCERATION
MO22RO.5	THYROID ADENOCARCINOMA
MO31RO.5B	THYROID CARCINOMA; SPONDYLITIS
FO31RO.5C	TRAUMA
FO31RO.5D	AORTIC BODY TUMOR
MO32RO.5B	HEMANGIO SARCOMA (SOFT TISSUE)
FO32RO.5C	ADENOCARCINOMA SALIVARY GLAND (CYLINDROMA)
FO32RO.5D	HEMANGIOSARCOMA (SPLEEN)
MO33RO.5B	EPIDERMOID CARCINOMA (ORAL)
FO33RO.5C	

A. RADIUM - 226

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
FO33RO.5D	527	8.70	0.0217	27	4	66		4697	119
MO34RO.5B	496	10.50	0.0196	25	5	66	4693		
FO34RO.5C	524	9.90	0.0215	27	4	66		4322	72
FO34RO.5D	508	9.70	0.0212	27	4	66		4628	110
MO35RO.5B	536	10.4	0.0205	29	12	66		4367	92
FO35RO.5C	532	9.00	0.0201	29	12	66	4475		
FO35RO.5D	532	10.2	0.0202	29	12	66	4475		
M101RO.5Y	88	4.32	0.0186	25	3	75	1467		
M102RO.5Y	93	4.44	0.0187	24	4	75	1437		
M103RO.5Y	90	3.61	0.0192	6	5	75	1425		
F104RO.5Y	88	4.09	0.0184	25	3	75	1467		
F105RO.5Y	88	4.08	0.0184	25	3	75	1467		
F106RO.5Y	93	3.60	0.0188	24	4	75	1437		
M107RO.5Y	93	3.69	0.0191	8	3	77	753		
M108RO.5Y	88	2.54	0.0185	19	1	78	436		
F109RO.5Y	90	3.45	0.0177	9	3	78	387		
F110RO.5Y	94	3.11	0.0195	8	8	78	235		
MO01R1.O	471	8.48	0.0618	20	4	53		5727	227
MO02R1.O	627	10.0	0.0876	16	11	53		4054	316
FO03R1.O	706	8.68	0.0576	10	3	54		3860	201
MO04R1.O	414	8.60	0.0642	7	4	54		2038	144
MO05R1.O	490	11.7	0.0436	22	6	54		3780	149
FO06R1.O	483	7.23	0.0584	27	7	54		5260	249
MO07R1.O	511	11.4	0.0651	24	8	54		3544	223
FO08R1.O	861	8.98	0.0559	21	12	54		2988	124
FO09R1.O	781	9.88	0.0521	11	4	55		4399	132
MO10R1.O	523	11.5	0.0573	27	7	55		4003	209
FO11R1.O	511	11.2	0.0522	20	12	55		5462	200
FO12R1.O	501	9.71	0.0444	17	1	56		3978	165
MO13R1.O	529	11.7	0.0527	4	3	64		3739	218
FO14R1.O	510	10.5	0.0701	23	10	64		1729	197
MO15R1.O	490	8.88	0.0797	4	2	65		893	109
FO16R1.O	501	8.99	0.0611	7	4	65		4557	223
MO17R1.O	494	11.40	0.0639	27	4	66	4721		
FO18R1.O	496	10.00	0.0589	25	5	66		3625	192
FO19R1.O	526	11.6	0.0682	13	10	66		3612	275
MO20R1.O	536	10.0	0.0610	29	12	66		4260	324
FO21R1.O	525	8.10	0.0633	26	1	67	4447		
MO22R1.O	484	10.9	0.0861	22	3	67	4392		
FO31R1.OB	509	10.40	0.0712	22	12	65		3009	209
M101R1.OY	88	4.09	0.0545	25	3	75	1467		

A. RADIUM - 226

DOG NUMBER	COMMENTS ON DEAD DOGS
FO33RO.5D	CHOLESTASIS
MO34RO.5B	
FO34RO.5C	MAMMARY CARCINOMA
FO34RO.5D	TRANSITIONAL CELL CARCINOMA
MO35RO.5B	UNDETERMINED (NO BONE TUMOR)
FO35RO.5C	
FO35RO.5D	
M101RO.5Y	
M102RO.5Y	
M103RO.5Y	
F104RO.5Y	
F105RO.5Y	
F106RO.5Y	
M107RO.5Y	
M108RO.5Y	
F109RO.5Y	
F110RO.5Y	
MOO1R1.O	MELANOMA ORAL CAVITY
MOO2R1.O	SEMINOMA
FOO3R1.O	MAMMARY GLAND CARCINOMA
MOO4R1.O	TRAUMA
MOO5R1.O	TRANSITIONAL CELL CARCINOMA,HYDRONEPHROSIS
FOO6R1.O	NEPHRITIS
MOO7R1.O	STATUS EPILEPTICUS
FOO8R1.O	LYMPHOSARCOMA
FOO9R1.O	PNEUMONIA
MO10R1.O	FIBROSARCOMA (GINGIVA)
FO11R1.O	MELANOMA (EYE); MAMMARY CARCINOMA
FO12R1.O	MELANOMA, GINGIVA
MO13R1.O	PROSTATIC CYST
FO14R1.O	UNDETERMINED (NO NEOPLASIA)
MO15R1.O	UNDETERMINED (NO NEOPLASIA)
FO16R1.O	LYMPHOSARCOMA
MO17R1.O	
FO18R1.O	MAMMARY CARCINOMA
FO19R1.O	OSTEOSARCOMA
MO20R1.O	CHONDROSARCOMA (NASAL CAVITY)
FO21R1.O	
MO22R1.O	
FO31R1.OB	STATUS EPILEPTICUS
M101R1.OY	

A. RADIUM - 226

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
M102R1.0Y	92	4.54	0.0546	1	4	75	1460		
M103R1.0Y	90	3.03	0.0564	6	5	75	1425		
F104R1.0Y	88	3.71	0.0541	25	3	75	1467		
F105R1.0Y	92	4.70	0.0528	1	4	75	1460		
F106R1.0Y	93	4.20	0.0557	24	4	75	1437		
M107R1.0Y	93	4.12	0.0575	8	3	77	753		
M108R1.0Y	88	2.52	0.0548	19	1	78	436		
F109R1.0Y	90	3.61	0.0544	9	3	78	387		
M111R1.0Y	90	2.95	0.0527	23	5	78	312		
M001R1.7	523	9.98	0.137	17	1	56		4438	455
M002R1.7	598	7.85	0.163	30	11	56		1273	155
M002R1.7A	493	12.0	0.222	6	3	63		3254	973
F003R1.7	473	13.1	0.165	20	12	55		3267	513
M004R1.7	514	6.20	0.163	20	12	55		5495	684
M005R1.7	511	10.1	0.151	20	12	55		4107	651
F006R1.7	491	7.9	0.152	20	12	55		3432	556
M007R1.7	598	7.17	0.163	30	11	56		3142	412
F008R1.7	491	9.50	0.154	20	12	55		2577	504
F009R1.7	598	7.55	0.168	30	11	56		3914	349
M010R1.7	590	9.57	0.167	30	11	56		557	145
M010R1.7A	545	10.6	0.183	7	1	59		4903	681
F011R1.7	598	8.17	0.165	30	11	56		5324	400
F012R1.7	590	8.95	0.167	30	11	56		2399	280
M101R1.7Y	92	4.19	0.163	1	4	75	1460		
M102R1.7Y	93	5.45	0.167	24	4	75	1437		
M103R1.7Y	90	2.84	0.167	6	5	75	1425		
F104R1.7Y	88	3.65	0.159	25	3	75	1467		
F105R1.7Y	88	3.66	0.158	25	3	75	1467		
F106R1.7Y	93	3.62	0.180	24	4	75	1437		
M107R1.7Y	93	3.77	0.166	16	3	77		8	19
M108R1.7Y	88	3.95	0.180	20	4	78	345		
F109R1.7Y	90	2.98	0.164	23	5	78	312		
F110R1.7Y	91	2.24	0.160	20	6	78	284		
M111R1.7Y	90	3.39	0.158	23	5	78	312		
M001R2.0	471	8.74	0.382	20	4	53		3440	1147
M002R2.0	592	8.21	0.387	16	11	53		3775	833
F003R2.0	541	8.53	0.347	10	3	54		4459	1163
M004R2.0	414	10.5	0.361	7	4	54		325	252
M004R2.0A	420	10.6	0.306	11	4	55		4368	1523

A. RADIUM - 226

DOG NUMBER	COMMENTS ON DEAD DOGS
M102R1.0Y	
M103R1.0Y	
F104R1.0Y	
F105R1.0Y	
F106R1.0Y	
M107R1.0Y	
M108R1.0Y	
F109R1.0Y	
M111R1.0Y	
M001R1.7	OBTURATING ABDOMINAL AORTA AND PULMONARY EMBOLISM
M002R1.7	LYMPHOSARCOMA
M002R1.7A	FIBROSARCOMA (GINGIVA)
F003R1.7	MAMMARY GLAND CARCINOMA
M004R1.7	NEPHRITIS
M005R1.7	OSTEOSARCOMA
F006R1.7	PULMONARY CALCIFICATION (NO BONE TUMOR)
M007R1.7	BACTERIAL TOXEMIA, INTERSTITIAL CELL ADENOMA
F008R1.7	DRUG ALLERGY
F009R1.7	PYOMETRA
M010R1.7	TRAUMA
M010R1.7A	UNDIFFERENTIATED MALIGNANCY (NON-SKELETAL);MELANOMA (EYE)
F011R1.7	MELANOMA (ORAL); THYROID CARCINOMA
F012R1.7	UNDETERMINED (NO BONE TUMOR)
M101R1.7Y	
M102R1.7Y	
M103R1.7Y	
F104R1.7Y	
F105R1.7Y	
F106R1.7Y	
M107R1.7Y	ANESTHESIA ACCIDENT
M108R1.7Y	
F109R1.7Y	
F110R1.7Y	
M111R1.7Y	
M001R2.0	HEMANGIOSARCOMA (SPLEEN)
M002R2.0	OSTEOSARCOMA
F003R2.0	RETICULUM CELL SARCOMA (NON-SKELETAL)
M004R2.0	PERFORATED ILEUM
M004R2.0A	OSTEOSARCOMA; VALVULAR ENDOCARDITIS

A. RADIUM - 226

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
M005R2.0	461	11.5	0.267	22 6 54		4703	1325
F006R2.0	486	10.6	0.360	27 7 54		4615	1685
M007R2.0	514	11.1	0.413	24 8 54		3425	1229
F008R2.0	572	6.95	0.331	21 12 54		4781	1328
F009R2.0	592	9.38	0.317	11 4 55		3998	1355
M010R2.0	523	9.95	0.345	27 7 55		3569	1627
F011R2.0	495	9.30	0.310	20 12 55		3297	971
F012R2.0	497	10.3	0.281	17 1 56		2948	989
M101R2.0Y	90	4.64	0.317	7 3 75	1485		
M102R2.0Y	90	4.27	0.324	7 3 75	1485		
M103R2.0Y	90	5.35	0.320	7 3 75	1485		
F104R2.0Y	90	4.36	0.317	7 3 75	1485		
F105R2.0Y	90	3.93	0.321	7 3 75	1485		
F106R2.0Y	89	4.19	0.309	14 3 75	1478		
M107R2.0Y	93	4.53	0.329	16 3 77	745		
M108R2.0Y	88	4.43	0.348	20 4 78	345		
F109R2.0Y	88	2.79	0.332	19 1 78	436		
F110R2.0Y	90	3.55	0.320	20 6 78	284		
M001R3.0	473	8.91	1.20	20 4 53		2850	3193
M002R3.0	470	9.02	1.21	16 11 53		2226	2303
F003R3.0	386	7.74	1.11	10 3 54		2497	3097
M004R3.0	412	11.7	1.16	7 4 54		1917	3148
M005R3.0	461	13.0	0.846	22 6 54		2955	3089
F006R3.0	486	9.75	1.14	27 7 54		1932	2995
M007R3.0	514	12.3	1.29	24 8 54		2099	4039
F008R3.0	542	7.76	1.03	21 12 54		2612	2555
F009R3.0	551	8.02	0.987	11 4 55		2487	2452
M010R3.0	525	10.1	1.06	27 7 55		1737	3115
F011R3.0	495	12.9	0.938	20 12 55		1610	1777
F012R3.0	497	11.4	0.883	17 1 56		1897	2185
M101R3.0Y	93	4.41	1.01	24 4 75	1437		
M102R3.0Y	93	5.40	1.01	24 4 75	1437		
M103R3.0Y	90	2.94	1.08	6 5 75	1425		
F104R3.0Y	88	3.74	1.02	25 3 75	1467		
F105R3.0Y	93	4.51	1.02	24 4 75	1437		
F106R3.0Y	90	3.25	1.07	6 5 75	1425		
M107R3.0Y	88	2.46	1.05	19 1 78	436		
M108R3.0Y	88	2.34	0.462	9 5 78	326		
F109R3.0Y	93	3.40	1.09	19 1 78	436		
F110R3.0Y	91	3.04	1.02	8 8 78	235		
F501R3.0+	1787	10.4	0.806	10 6 75	1390		

A. RADIUM - 226

DOG NUMBER	COMMENTS ON DEAD DOGS
M005R2.0	OSTEOSARCOMA, ADRENAL CORTICAL CARCINOMA
F006R2.0	EPIDERMOID CARCINOMA (TYMPANIC BULLA)
M007R2.0	OSTEOSARCOMA, CUSHING SYNDROME
F008R2.0	UNDIFFERENTIATED MALIGNANCY, SMALL INTESTINE
F009R2.0	MAMMARY CARCINOMA
M010R2.0	OSTEOSARCOMA
F011R2.0	OSTEOSARCOMA
F012R2.0	MAMMARY ADENOCARCINOMA
M101R2.0Y	
M102R2.0Y	
M103R2.0Y	
F104R2.0Y	
F105R2.0Y	
F106R2.0Y	
M107R2.0Y	
M108R2.0Y	
F109R2.0Y	
F110R2.0Y	
M001R3.0	OSTEOSARCOMA
M002R3.0	OSTEOSARCOMA
F003R3.0	OSTEOSARCOMA
M004R3.0	OSTEOSARCOMA
M005R3.0	OSTEOSARCOMA
F006R3.0	OSTEOSARCOMA
M007R3.0	OSTEOSARCOMA
F008R3.0	OSTEOSARCOMA
F009R3.0	OSTEOSARCOMA
M010R3.0	OSTEOSARCOMA
F011R3.0	PYOMETRITIS + SECONDARY PERITONITIS
F012R3.0	OSTEOSARCOMA
M101R3.0Y	
M102R3.0Y	
M103R3.0Y	
F104R3.0Y	
F105R3.0Y	
F106R3.0Y	
M107R3.0Y	
M108R3.0Y	
F109R3.0Y	
F110R3.0Y	
F501R3.0+	

A. RADIUM - 226

DOG NUMBER	INJECTION AGE (DAYS)	INJECTION WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DAYS SINCE INJECTION DEATH	DOSE TO SKELETON (RADS)
F502R3.0+	1918	8.26	0.972	22 9 76	920		
F503R3.0+	1836	10.0	1.08	29 11 77	487		
F504R3.0+	1713	9.33	1.02	5 10 78	177		
F505R3.0+	1814	8.15	1.23	2 11 78	149		
M506R3.0+	1716	9.72	1.00	5 10 78		21	36
M507R3.0+	1708	10.8	1.01	5 10 78	177		
M508R3.0+	1711	11.5	1.01	5 10 78	177		
M509R3.0+	1829	11.8	1.23	2 11 78	149		
M510R3.0+	1827	10.6	1.23	2 11 78	149		
M001R4.0	471	9.08	3.51	20 4 53		1606	8767
M002R4.0	470	9.53	3.55	16 11 53		1884	8200
F003R4.0	384	8.65	3.33	10 3 54		490	2944
F003R4.0A	598	7.20	3.10	30 11 56		1614	5140
M004R4.0	408	8.83	3.47	7 4 54		1518	8084
M005R4.0	461	13.2	2.42	22 6 54		1659	6007
F006R4.0	486	8.55	3.44	27 7 54		1939	9511
M007R4.0	453	9.55	3.88	24 8 54		1647	7792
F008R4.0	474	8.94	3.14	21 12 54		1324	6153
F009R4.0	542	8.53	3.02	11 4 55		1471	5460
M010R4.0	527	10.8	3.28	27 7 55		1553	10109
F011R4.0	491	10.4	2.84	20 12 55		1469	7031
F012R4.0	496	9.61	2.81	17 1 56		1435	5169
F501R4.0+	1787	10.5	2.50	10 6 75		303	1330
F502R4.0+	1933	9.09	2.96	22 9 76	920		
F503R4.0+	1836	10.9	3.44	29 11 77	487		
F504R4.0+	1735	7.93	1.98	10 1 78	445		
F505R4.0+	1876	11.6	2.89	5 10 78	177		
M506R4.0+	1881	10.1	2.97	5 10 78	177		
M507R4.0+	1823	11.2	3.04	9 5 78	326		
M508R4.0+	1845	10.5	2.99	5 10 78	177		
M509R4.0+	1827	13.2	3.65	2 11 78	149		
M510R4.0+	1807	12.2	3.61	2 11 78	149		
M001R5.0	473	9.87	10.5	20 4 53		908	19924
M002R5.0	470	8.85	10.8	16 11 53		1380	24095
F003R5.0	380	7.82	10.1	10 3 54		481	9529
M004R5.0	408	8.90	10.6	7 4 54		1091	21889
M005R5.0	458	10.9	10.1	22 6 54		1220	20577
F006R5.0	486	9.66	10.2	27 7 54		1015	20552
M007R5.0	453	8.85	11.9	24 8 54		1288	22277

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DOG NUMBER	COMMENTS ON DEAD DOGS
F502R3.0+	
F503R3.0+	
F504R3.0+	
F505R3.0+	
M506R3.0+	ANESTHETIC ACCIDENT
M507R3.0+	
M508R3.0+	
M509R3.0+	
M510R3.0+	
M001R4.0	OSTEOSARCOMA
M002R4.0	OSTEOSARCOMA
F003R4.0	CANINE DISTEMPER
F003R4.0A	OSTEOSARCOMA
M004R4.0	OSTEOSARCOMA
M005R4.0	OSTEOSARCOMA
F006R4.0	OSTEOSARCOMA
M007R4.0	OSTEOSARCOMA
F008R4.0	OSTEOSARCOMA
F009R4.0	OSTEOSARCOMA
M010R4.0	OSTEOSARCOMA
F011R4.0	OSTEOSARCOMA
F012R4.0	OSTEOSARCOMA
F501R4.0+	PERITONITIS
F502R4.0+	
F503R4.0+	
F504R4.0+	
F505R4.0+	
M506R4.0+	
M507R4.0+	
M508R4.0+	
M509R4.0+	
M510R4.0+	
M001R5.0	OSTEOSARCOMA
M002R5.0	OSTEOSARCOMA
F003R5.0	CANINE DISTEMPER
M004R5.0	OSTEOSARCOMA
M005R5.0	OSTEOSARCOMA
F006R5.0	OSTEOSARCOMA
M007R5.0	OSTEOSARCOMA

A. RADIUM - 226

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
F008R5.0	474	7.76	9.68	21 12 54		968	15419
F009R5.0	420	9.16	9.48	11 4 55		1288	21255
M010R5.0	527	10.7	10.2	27 7 55		825	14905
F501R5.0+	1827	12.8	10.2	16 8 77		266	3456
F502R5.0+	1812	9.65	9.97	29 11 77	487		
F503R5.0+	1819	10.8	6.31	10 1 78		419	3470
F504R5.0+	1855	7.52	9.22	9 5 78	326		

A. RADIUM - 226

DOG NUMBER	COMMENTS ON DEAD DOGS
F008R5.0	OSTEOSARCOMA
F009R5.0	OSTEOSARCOMA + ANEMIA
M010R5.0	OSTEOSARCOMA + FRACTURED MANDIBLE
F501R5.0+	NEPHRITIS
F502R5.0+	
F503R5.0+	NEPHRITIS
F504R5.0+	

B. PLUTONIUM - 239 *

DOG NUMBER	INJECTION AGE (DAYS)	INJECTION WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DAYS SINCE INJECTION DEATH	DOSE TO SKELETON (RADS)
M001PO.O	443	9.70		1 12 52		4003	
F002PO.O	424	6.36		2 3 53		2755	
M003PO.O	515	10.8		1 6 53		5362	
M004PO.O	426	10.7		16 9 53		5138	
F005PO.O	620	9.75		14 10 53		4088	
F006PO.O	410	5.59		12 5 54		4490	
F007PO.O	515	6.90		25 10 54		5344	
M008PO.O	585	10.9		15 3 55		4072	
F009PO.O	574	11.0		9 9 55		3032	
F010PO.O	658	11.0		22 11 55		3971	
M011PO.O	602	10.3		24 4 56		3821	
M012PO.O	630	10.9		29 5 56		4143	
F013PO.O	517	9.47		4 3 64		5361	
F014PO.O	452	9.89		12 5 64		4105	
M015PO.O	527	12.1		23 10 64		3750	
M016PO.O	486	13.9		7 4 65		4756	
M017PO.O	551	12.2		8 11 66	4526		
F018PO.O	536	11.4		29 11 66	4505		
M019PO.O	536	13.1		29 11 66	4505		
F020PO.O	546	8.50		29 12 66		3748	
M021PO.O	549	13.3		26 1 67		4157	
F022PO.O	489	10.6		25 5 67	4328		
M031PO.OB	452	11.8		12 5 64		1763	
M031PO.OC	452	12.6		12 5 64		3629	
M032PO.OB	452	11.2		12 5 64		4840	
M032PO.OC	542	10.3		21 9 65	4939		
M033PO.OB	517	12.1		21 9 65		4923	
M033PO.OC	503	11.70		18 11 65		4164	
M034PO.OB	525	13.5		26 1 67	4447		
M034PO.OC	484	12.7		22 3 67		4139	
M035PO.OB	484	12.5		22 3 67	4392		
M035PO.OC	484	13.1		22 3 67		3501	
M036PO.OB	489	11.0		25 5 67		2525	
M036PO.OC	485	12.2		25 5 67	4328		
M037PO.OB	507	11.7		22 6 67		4179	
M037PO.OC	493	10.4		22 6 67	4300		
M038PO.OB	529	10.7		16 11 67		3623	
M038PO.OC	529	12.2		16 11 67		3382	
M039PO.OB	503	10.7		21 12 67	4118		
M039PO.OC	503	10.1		21 12 67	4118		
M040PO.OB	484	10.3		30 7 68	3896		
M040PO.OC	552	11.4		9 1 69		3377	
M041PO.OB	560	9.49		17 1 69	3725		

B. PLUTONIUM - 239 *

DOG NUMBER	COMMENTS ON DEAD DOGS
MO01PO.O	SPLENIC RUPTURE, METASTATIC SEMINOMA
FO02PO.O	ANESTHETIC ACCIDENT
MO03PO.O	PANCREATIC ADENOCARCINOMA
MO04PO.O	THYROID CARCINOMA, NEPHRITIS
FO05PO.O	ADRENAL CORTICAL CARCINOMA
FO06PO.O	OBTURATING PULMONARY EMBOLISM
FO07PO.O	RHABDOMYOSARCOMA
MO08PO.O	CIRCULATORY FAILURE
FO09PO.O	PULMONARY EMBOLISM, NEPHRITIS
FO10PO.O	LEUKEMIA
MO11PO.O	FIBROSARCOMA (SPLEEN)
MO12PO.O	TESTICULAR CARCINOMA
FO13PO.O	OSTEOSARCOMA
FO14PO.O	SURGICAL SHOCK; PYOMETRA
MO15PO.O	TRANSITIONAL CELL CARCINOMA
MO16PO.O	SENILITY
MO17PO.O	
FO18PO.O	
MO19PO.O	
FO20PO.O	PLEURAL EFFUSION
MO21PO.O	AORTIC BODY TUMOR
FO22PO.O	
MO31PO.OB	STATUS EPILEPTICUS; BILE DUCT OBSTRUCTION
MO31PO.OC	MALIGNANT MELANOMA (ORAL)
MO32PO.OB	CARDIAC INSUFFICIENCY
MO32PO.OC	
MO33PO.OB	SENILITY
MO33PO.OC	UNDETERMINED (NO BONE TUMOR)
MO34PO.OB	
MO34PO.OC	UNDETERMINED (NO BONE TUMOR)
MO35PO.OB	
MO35PO.OC	PARALYSIS (UNDETERMINED ETIOLOGY) (NO BONE TUMOR)
MO36PO.OB	STATUS EPILEPTICUS
MO36PO.OC	
MO37PO.OB	UNDETERMINED (NO BONE TUMOR)
MO37PO.OC	
MO38PO.OB	TRANSITIONAL CELL CARCINOMA
MO38PO.OC	PNEUMONIA
MO39PO.OB	
MO39PO.OC	
MO40PO.OB	
MO40PO.OC	PERIARTERITIS
MO41PO.OB	

B. PLUTONIUM - 239 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
MO42PO.O	479	14.0		24 4 74	1802		
MO42PO.OB	338	11.6		25 4 69		32	
MO43PO.O	479	13.8		24 4 74	1802		
MO44PO.O	479	12.7		24 4 74	1802		
MO45PO.O	497	11.5		29 8 74		1537	
MO46PO.O	497	11.5		29 8 74	1675		
MO47PO.O	497	11.3		29 8 74	1675		
MO48PO.O	497	11.7		29 8 74	1675		
MO81PO.OY	105	7.10		9 3 72	2578		
FO82PO.OY	105	7.30		9 3 72	2578		
FO83PO.OY	91	3.97		25 4 72	2531		
FO84PO.OY	89	3.67		25 4 72	2531		
MO86PO.OY	91	4.37		25 4 72	2531		
F101PO.OY	93	2.97		19 9 74	1654		
M102PO.OY	89	4.65		21 11 74	1591		
F103PO.OY	91	2.54		19 9 74	1654		
M104PO.OY	89	4.68		26 11 74	1586		
M105PO.OY	92	4.90		27 4 76	1068		
F106PO.OY	92	3.46		13 4 76	1082		
M107PO.OY	90	4.07		27 4 76	1068		
F108PO.OY	91	4.28		16 12 76	835		
M109PO.OY	91	4.08		16 12 76	835		
FO13PO.1	515	9.46	0.00068	4 3 64		4492	3
FO14PO.1	452	10.3	0.00055	12 5 64		4503	2
MO15PO.1	536	9.67	0.00071	23 10 64		4319	3
MO16PO.1	501	12.0	0.00059	7 4 65		4146	2
MO17PO.1	551	12.2	0.00057	8 11 66		4346	2
FO18PO.1	536	9.28	0.00070	29 11 66		4221	3
MO19PO.1	536	11.6	0.00063	29 11 66	4505		
FO20PO.1	536	9.80	0.00075	29 12 66		3939	3
MO21PO.1	538	11.3	0.00059	26 1 67	4447		
FO22PO.1	489	9.8	0.00059	25 5 67		2968	2
MO31PO.1B	517	12.2	0.00068	4 3 64		2760	2
FO32PO.1B	549	10.4	0.00059	18 11 65	4881		
MO33PO.1B	549	10.8	0.00079	18 11 65		4156	3
FO34PO.1B	533	11.1	0.00058	8 11 66		3292	2
MO35PO.1B	489	10.3	0.00059	25 5 67	4328		
FO36PO.1B	493	9.79	0.00060	22 6 67		3600	4
MO37PO.1B	493	11.3	0.00059	22 6 67	4300		
FO38PO.1B	513	9.52	0.00057	21 12 67		1979	1
MO39PO.1B	490	10.5	0.00058	21 12 67	4118		

B. PLUTONIUM - 239 *

DOG NUMBER	COMMENTS ON DEAD DOGS
MO42PO.O	
MO42PO.OB	SPECIAL STUDY
MO43PO.O	
MO44PO.O	
MO45PO.O	STATUS EPILEPTICUS
MO46PO.O	
MO47PO.O	
MO48PO.O	
MO81PO.OY	
FO82PO.OY	
FO83PO.OY	
FO84PO.OY	
MO86PO.OY	
F101PO.OY	
M102PO.OY	
F103PO.OY	
M104PO.OY	
M105PO.OY	
F106PO.OY	
M107PO.OY	
F108PO.OY	
M109PO.OY	
FO13PO.1	TRANSITIONAL CELL CARCINOMA; PERITONITIS
FO14PO.1	CHONDROSARCOMA (PROXIMAL HUMERUS)
MO15PO.1	PANCREATIC DYSTROPHY
MO16PO.1	EPIDERMOID CARCINOMA (FRONTAL SINUS)
MO17PO.1	UNDIFFERENTIATED SARCOMA (SOFT TISSUE)
FO18PO.1	MALIGNANT MELANOMA (ORAL)
MO19PO.1	
FO20PO.1	MAMMARY CARCINOMA
MO21PO.1	
FO22PO.1	ACCIDENTAL STRANGULATION
MO31PO.1B	STATUS EPILEPTICUS
FO32PO.1B	
MO33PO.1B	BONE MARROW APLASIA
FO34PO.1B	CHRONIC PANCREATITIS
MO35PO.1B	
FO36PO.1B	INHALATION PNEUMONIA
MO37PO.1B	
FO38PO.1B	TRAUMA
MO39PO.1B	

B. PLUTONIUM - 239 *

DOG NUMBER	INJECTION AGE (DAYS)	INJECTION WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DAYS SINCE INJECTION DEATH	DOSE TO SKELETON (RADS)
MO44PO.1B	500	10.9	0.00057	8 8 73	2061		
FO44PO.1C	569	8.34	0.00072	2 12 70	3041		
MO45PO.1B	504	13.5	0.00122	30 5 74	1766		
FO45PO.1C	500	9.00	0.00051	8 8 73	2061		
MO46PO.1B	504	13.2	0.00120	30 5 74	1766		
FO46PO.1C	500	10.2	0.00057	8 8 73	2061		
FO47PO.1	500	9.34	0.00051	8 8 73	2061		
FO48PO.1	527	10.9	0.00120	30 5 74	1766		
FO49PO.1	504	9.71	0.00124	30 5 74	1766		
FO13PO.2	517	9.44	0.00206	4 3 64		3221	7
FO14PO.2	516	7.44	0.00173	12 5 64		3983	7
MO15PO.2	505	10.9	0.00201	23 10 64		4808	9
MO16PO.2	500	11.4	0.00163	7 4 65		2841	5
MO17PO.2	533	11.8	0.00171	8 11 66		4391	7
FO18PO.2	530	9.46	0.00200	29 11 66	4505		
MO19PO.2	530	12.1	0.00198	29 11 66		4392	8
FO20PO.2	532	8.30	0.00224	29 12 66		4299	9
MO21PO.2	538	12.1	0.00181	26 1 67	4447		
FO22PO.2	485	8.3	0.00176	25 5 67		4080	7
MO31PO.2B	515	10.7	0.00185	4 3 64		2640	5
FO31PO.2C	452	11.9	0.00169	12 5 64		4971	8
FO31PO.2D	429	9.35	0.00186	12 5 64		5378	9
MO32PO.2B	549	13.60	0.00178	18 11 65		3591	6
FO32PO.2C	494	10.1	0.00183	4 2 65		3881	7
FO32PO.2D	490	8.04	0.00193	4 2 65	5168		
MO33PO.2B	513	14.50	0.00178	18 11 65		2776	5
FO33PO.2C	549	12.50	0.00176	18 11 65		4615	8
FO33PO.2D	513	12.70	0.00178	18 11 65	4881		
MO34PO.2B	533	12.7	0.00170	8 11 66		3934	7
FO34PO.2C	533	11.5	0.00172	8 11 66		4515	7
FO34PO.2D	519	9.92	0.00167	8 11 66	4526		
MO35PO.2B	489	11.2	0.00173	25 5 67	4328		
FO35PO.2C	507	10.5	0.00175	22 6 67		2593	5
FO35PO.2D	507	9.10	0.00175	22 6 67	4300		
MO36PO.2B	479	12.9	0.00177	25 5 67	4328		
FO36PO.2C	493	10.4	0.00177	22 6 67		3291	6
FO36PO.2D	569	8.74	0.00146	16 11 67		3351	5
MO37PO.2B	529	10.6	0.00149	16 11 67		2804	4
FO37PO.2C	529	10.1	0.00150	16 11 67	4153		
FO37PO.2D	529	7.14	0.00153	16 11 67	4153		
MO38PO.2B	517	10.0	0.00152	16 11 67		3546	5

B. PLUTONIUM - 239 *

DOG NUMBER	COMMENTS ON DEAD DOGS
MO44PO.1B	
FO44PO.1C	
MO45PO.1B	
FO45PO.1C	
MO46PO.1B	
FO46PO.1C	
FO47PO.1	
FO48PO.1	
FO49PO.1	
FO13PO.2	INTESTINAL ILEUS
FO14PO.2	ENTERITIS
MO15PO.2	ATHEROSCLEROSIS
MO16PO.2	ENCEPHALITIS
MO17PO.2	LYMPHOSARCOMA
FO18PO.2	
MO19PO.2	UNDETERMINED (NO SKELETAL NEOPLASIA)
FO20PO.2	THROMBOEMBOLISM
MO21PO.2	
FO22PO.2	RETICULUM CELL SARCOMA (LIVER)
MO31PO.2B	MELANOMA (ORAL)
FO31PO.2C	PULMONARY THROMBO-EMBOLISM
FO31PO.2D	UNDIFFERENTIATED MALIGNANCY (SOFT TISSUE)
MO32PO.2B	HEMANGIOSARCOMA (SPLEEN)
FO32PO.2C	MAMMARY CARCINOMA; LUNG THROMBO-EMBOLISM
FO32PO.2D	
MO33PO.2B	PNEUMONIA
FO33PO.2C	RENAL HEMORRHAGE
FO33PO.2D	
MO34PO.2B	PROSTATIC CARCINOMA
FO34PO.2C	LUNG CARCINOMA
FO34PO.2D	
MO35PO.2B	
FO35PO.2C	LUNG CARCINOMA
FO35PO.2D	
MO36PO.2B	
FO36PO.2C	ENTERITIS
FO36PO.2D	INTESTINAL PERFORATION
MO37PO.2B	HEMANGIOSARCOMA (ABDOMINAL CAVITY)
FO37PO.2C	
FO37PO.2D	
MO38PO.2B	PLASMA CELL MYELOMA (HUMERUS)

B. PLUTONIUM - 239 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
FO38PO.2C	503	7.95	0.00211	21 12 67	4118		
FO38PO.2D	499	9.08	0.00176	21 12 67		2880	5
MO39PO.2B	542	11.6	0.00214	2 12 70		2916	5
FO39PO.2C	499	9.46	0.00173	21 12 67	4118		
FO39PO.2D	499	9.34	0.00176	21 12 67		3401	6
MO42PO.2B	504	9.42	0.00182	8 8 73	2061		
FO42PO.2C	589	9.55	0.00176	4 9 69	3495		
MO43PO.2B	497	11.0	0.00179	24 4 74	1802		
FO43PO.2C	542	9.50	0.00239	2 12 70	3041		
MO44PO.2B	540	11.6	0.00177	17 11 71		97	<1
MO44PO.2C	491	12.0	0.00188	24 4 74	1802		
MO44PO.2D	488	11.6	0.00184	24 4 74	1802		
MO45PO.2B	488	11.6	0.00184	24 4 74	1802		
MO45PO.2C	482	11.4	0.00188	24 4 74	1802		
MO46PO.2B	482	11.1	0.00179	24 4 74	1802		
FO13PO.5	517	9.93	0.00540	4 3 64		2388	15
FO13PO.5A	501	11.2	0.00495	23 9 70	3111		
FO14PO.5	516	9.98	0.00493	12 5 64		4537	21
MO15PO.5	505	8.41	0.00627	23 10 64		4588	28
MO16PO.5	501	12.6	0.00521	7 4 65		4062	21
MO17PO.5	533	13.4	0.00506	8 11 66	4526		
FO18PO.5	530	8.98	0.00594	29 11 66		4333	25
MO19PO.5	530	11.9	0.00645	29 11 66		3829	24
FO20PO.5	532	9.30	0.00553	29 12 66		3490	20
MO21PO.5	538	9.80	0.00526	26 1 67	4447		
FO22PO.5	485	8.1	0.00525	25 5 67	4328		
MO25PO.5	509	9.70	0.00539	30 1 74	1886		
MO26PO.5	509	9.96	0.00536	30 1 74	1886		
MO31PO.5B	515	10.5	0.00549	4 3 64		1648	15
FO31PO.5C	494	8.44	0.00572	4 2 65		2546	16
MO32PO.5B	549	13.60	0.00546	18 11 65		2270	14
FO33PO.5B	503	10.10	0.00559	18 11 65		4509	24
MO34PO.5B	530	12.5	0.00642	29 11 66		1920	14
FO35PO.5B	501	9.54	0.00520	22 6 67	4300		
MO36PO.5B	479	11.5	0.00527	25 5 67		3885	20
FO37PO.5B	517	8.39	0.00454	16 11 67	4153		
MO38PO.5B	517	10.5	0.00448	16 11 67		3497	35
FO39PO.5B	490	10.9	0.00528	21 12 67	4118		
MO42PO.5B	542	13.1	0.00675	2 12 70	3041		
MO42PO.5C	542	12.2	0.00668	2 12 70	3041		
FO42PO.5D	542	9.71	0.00668	2 12 70	3041		

B. PLUTONIUM - 239 *

DOG NUMBER	COMMENTS ON DEAD DOGS
FO38PO.2C	
FO38PO.2D	NEPHRITIS; PANCREATITIS
MO39PO.2B	HEMANGIOSARCOMA (HEART)
FO39PO.2C	
FO39PO.2D	RHABDOMYOSARCOMA
MO42PO.2B	
FO42PO.2C	
MO43PO.2B	
FO43PO.2C	
MO44PO.2B	SPECIAL STUDY
MO44PO.2C	
MO44PO.2D	
MO45PO.2B	
MO45PO.2C	
MO46PO.2B	
FO13PO.5	MAMMARY CARCINOMA
FO13PO.5A	
FO14PO.5	CHONDROSARCOMA (NASAL CAVITY)
MO15PO.5	AORTIC THROMBOEMBOLISM; THYROID CARCINOMA
MO16PO.5	CHROMAPHOBE ADENOMA
MO17PO.5	
FO18PO.5	HEMANGIO SARCOMA (SOFT TISSUE)
MO19PO.5	OSTEOSARCOMA
FO20PO.5	EPIDERMOID CARCINOMA (ORAL)
MO21PO.5	
FO22PO.5	
MO25PO.5	
MO26PO.5	
MO31PO.5B	STATUS EPILEPTICUS
FO31PO.5C	SPECIAL STUDY
MO32PO.5B	SPECIAL STUDY
FO33PO.5B	MAMMARY CARCINOMA
MO34PO.5B	SPECIAL STUDY
FO35PO.5B	
MO36PO.5B	OSTEOSARCOMA (NASAL CAVITY)
FO37PO.5B	
MO38PO.5B	UNDETERMINED (NO BONE TUMOR)
FO39PO.5B	
MO42PO.5B	
MO42PO.5C	
FO42PO.5D	

B. PLUTONIUM - 239 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
FO43PO.5B	545	11.6	0.00484	3 10 69	3466		
FO43PO.5C	537	10.7	0.00480	3 10 69	3466		
MO43PO.5D	500	12.0	0.00546	8 8 73	2061		
MO44PO.5B	445	11.5	0.00360	3 6 69		99	<1
FO44PO.5C	504	8.48	0.00604	8 8 73	2061		
MO45PO.5B	472	10.3	0.00350	3 6 69		42	<1
FO45PO.5C	540	10.0	0.00516	17 11 71		35	<1
MO46PO.5B	484	11.8	0.00336	3 6 69		7	<1
FO46PO.5C	540	9.15	0.00516	17 11 71		7	<1
MO47PO.5	568	11.9	0.00524	8 8 74	1696		
MO48PO.5	568	12.1	0.00546	8 8 74	1696		
FO49PO.5	569	9.10	0.00537	8 8 74	1696		
FO50PO.5	568	12.8	0.00541	8 8 74	1696		
MO51PO.5	506	11.9	0.00552	29 8 74	1675		
MO52PO.5	506	10.4	0.00549	29 8 74	1675		
MO53PO.5	498	13.2	0.00515	29 8 74	1675		
MO54PO.5	497	10.8	0.00551	29 8 74	1675		
FO55PO.5	533	9.65	0.00547	17 10 74	1626		
FO56PO.5	533	9.56	0.00552	17 10 74	1626		
FO57PO.5	523	8.14	0.00524	17 10 74	1626		
F101PO.5Y	93	2.74	0.00617	19 9 74	1654		
M102PO.5Y	91	3.43	0.00618	19 9 74	1654		
F103PO.5Y	91	3.39	0.00611	19 9 74	1654		
M104PO.5Y	90	3.43	0.00525	27 4 76	1068		
M105PO.5Y	89	4.17	0.00570	26 11 74	1586		
F106PO.5Y	89	4.51	0.00580	26 11 74	1586		
F107PO.5Y	94	3.53	0.00553	22 9 76	920		
M108PO.5Y	91	4.47	0.00484	16 12 76	835		
F109PO.5Y	88	3.95	0.00542	20 4 78	345		
M110PO.5Y	90	4.48	0.00521	9 3 78	387		
F111PO.5Y	88	3.67	0.00533	23 5 78	312		
FO14PO.7	533	8.98	0.00947	22 7 69	3539		
MO15PO.7	533	10.3	0.00941	22 7 69		3471	33
MO16PO.7	516	11.9	0.0102	4 9 69	3495		
MO17PO.7	540	8.04	0.0103	3 10 69	3466		
FO18PO.7	531	9.66	0.00942	22 7 69	3539		
MO19PO.7	501	11.6	0.0104	23 9 70		1737	22
FO20PO.7	521	9.18	0.00926	22 7 69	3539		
MO21PO.7	499	11.1	0.0104	23 9 70	3111		
FO22PO.7	538	9.69	0.0108	4 9 69	3495		
FO23PO.7	538	9.56	0.0108	4 9 69	3495		

B. PLUTONIUM - 239 *

DOG NUMBER	COMMENTS ON DEAD DOGS
FO43PO.5B	
FO43PO.5C	
MO43PO.5D	
MO44PO.5B	SPECIAL STUDY
FO44PO.5C	
MO45PO.5B	SPECIAL STUDY
FO45PO.5C	SPECIAL STUDY
MO46PO.5B	SPECIAL STUDY
FO46PO.5C	SPECIAL STUDY
MO47PO.5	
MO48PO.5	
FO49PO.5	
FO5OPO.5	
MO51PO.5	
MO52PO.5	
MO53PO.5	
MO54PO.5	
FO55PO.5	
FO56PO.5	
FO57PO.5	
F1O1PO.5Y	
M1O2PO.5Y	
F1O3PO.5Y	
M1O4PO.5Y	
M1O5PO.5Y	
F1O6PO.5Y	
F1O7PO.5Y	
M1O8PO.5Y	
F1O9PO.5Y	
M11OPO.5Y	
F111PO.5Y	
FO14PO.7	
MO15PO.7	CHONDROSARCOMA (NASAL CAVITY)
MO16PO.7	
MO17PO.7	
FO18PO.7	
MO19PO.7	STRANGULATED HERNIA
FO2OPO.7	
MO21PO.7	
FO22PO.7	
FO23PO.7	

B. PLUTONIUM - 239 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
FO24PO.7	516	8.90	0.0110	4	9	69	3495		
MO25PO.7	506	10.9	0.0117	8	8	73		2042	28
MO26PO.7	494	10.2	0.0112	20	9	73	2018		
MO27PO.7	494	11.9	0.0116	20	9	73	2018		
FO28PO.7	494	10.6	0.0110	20	9	73	2018		
FO29PO.7	493	8.63	0.0113	20	9	73	2018		
FO30PO.7	487	9.91	0.0113	20	9	73	2018		
MO31PO.7	521	13.2	0.00956	4	12	73	1943		
MO32PO.7	521	9.46	0.00967	4	12	73	1943		
MO33PO.7	509	10.7	0.0103	30	1	74	1886		
MO34PO.7	521	10.1	0.00979	4	12	73	1943		
FO35PO.7	521	10.6	0.00981	4	12	73	1943		
FO36PO.7	521	11.1	0.00999	4	12	73	1943		
MO37PO.7	520	11.6	0.00999	4	12	73	1943		
FO38PO.7	520	11.4	0.00995	4	12	73	1943		
FO39PO.7	512	8.24	0.00969	4	12	73	1943		
MO40PO.7	512	10.7	0.00990	4	12	73	1943		
MO41PO.7	533	11.9	0.0105	30	1	74	1886		
MO42PO.7	533	11.6	0.0106	30	1	74	1886		
MO43PO.7	533	10.1	0.0106	30	1	74	1886		
FO44PO.7	533	10.2	0.0105	30	1	74	1886		
MO45PO.7	509	10.8	0.0104	30	1	74	1886		
FO46PO.7	509	10.2	0.0105	30	1	74	1886		
FO47PO.7	508	8.39	0.0103	30	1	74	1886		
MO48PO.7	502	10.30	0.00910	5	3	74	1852		
MO49PO.7	471	12.30	0.00990	5	3	74	1852		
FO50PO.7	522	9.33	0.0112	29	8	74	1675		
FO51PO.7	522	11.8	0.0105	29	8	74	1675		
MO01P1.0	443	9.41	0.0150	1	12	52		4572	66
FO02P1.0	422	6.85	0.0163	2	3	53		4810	74
MO03P1.0	515	8.00	0.0165	1	6	53		4292	68
MO04P1.0	608	9.97	0.0139	16	9	53		4549	60
FO05P1.0	620	8.80	0.0142	14	10	53		1539	27
FO05P1.0A	472	11.0	0.0168	3	9	58		3764	63
FO06P1.0	410	7.38	0.0140	12	5	54		4292	58
FO07P1.0	510	6.36	0.0167	25	10	54		3981	65
MO08P1.0	453	10.6	0.0172	15	3	55		3367	50
FO09P1.0	556	7.87	0.0168	9	9	55		2257	43
FO10P1.0	641	12.00	0.0152	22	11	55		3649	56
MO11P1.0	602	8.90	0.0157	24	4	56		5160	76
MO12P1.0	629	9.67	0.0167	29	5	56		2374	44

B. PLUTONIUM - 239 *

DOG NUMBER	COMMENTS ON DEAD DOGS
FO24PO.7	
MO25PO.7	STATUS EPILEPTICUS
MO26PO.7	
MO27PO.7	
FO28PO.7	
FO29PO.7	
FO3OPO.7	
MO31PO.7	
MO32PO.7	
MO33PO.7	
MO34PO.7	
FO35PO.7	
FO36PO.7	
MO37PO.7	
FO38PO.7	
FO39PO.7	
MO4OPO.7	
MO41PO.7	
MO42PO.7	
MO43PO.7	
FO44PO.7	
MO45PO.7	
FO46PO.7	
FO47PO.7	
MO48PO.7	
MO49PO.7	
FO5OPO.7	
FO51PO.7	
MOO1P1.O	OSTEOSARCOMA
FOO2P1.O	CIRCULATORY FAILURE
MOO3P1.O	OSTEOSARCOMA
MOO4P1.O	BILE DUCT CARCINOMA
FOO5P1.O	COLITIS, ENTERITIS + SECONDARY HEPATIC NECROSIS
FOO5P1.OA	THYROID CARCINOMA
FOO6P1.O	CARCINOMA OF COLON
FOO7P1.O	TRAUMA LYMPHADENOPHATHY
MOO8P1.O	OSTEOSARCOMA
FOO9P1.O	OSTEOSARCOMA
FO1OP1.O	MAMMARY CARCINOMA
MO11P1.O	THYROID CARCINOMA
MO12P1.O	CHRONIC PANCREATITIS

B. PLUTONIUM - 239 *

DOG NUMBER	INJECTION AGE (DAYS)	INJECTION WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DAYS SINCE INJECTION DEATH	DOSE TO SKELETON (RADS)
MO13P1.0	504	12.7	0.0153	3 9 58		5277	75
FO14P1.0	533	10.4	0.0141	22 7 69	3539		
MO15P1.0	516	12.8	0.0159	4 9 69	3495		
MO16P1.0	516	10.6	0.0165	4 9 69	3495		
MO17P1.0	537	10.9	0.0151	3 10 69	3466		
FO18P1.0	531	9.89	0.0140	22 7 69	3539		
MO19P1.0	501	9.82	0.0159	23 9 70	3111		
FO20P1.0	521	10.4	0.0141	22 7 69		3482	50
MO21P1.0	499	10.0	0.0156	23 9 70	3111		
FO22P1.0	521	9.04	0.0139	22 7 69	3539		
FO23P1.0	538	11.2	0.0163	4 9 69	3495		
FO24P1.0	516	10.4	0.0163	4 9 69		3308	55
MO25P1.0	504	11.0	0.0168	8 8 73	2061		
F101P1.0Y	93	2.23	0.0171	19 9 74	1654		
M102P1.0Y	91	2.83	0.0171	19 9 74	1654		
F103P1.0Y	89	3.56	0.0137	21 11 74	1591		
M104P1.0Y	89	5.14	0.0158	21 11 74	1591		
M105P1.0Y	91	5.19	0.0143	2 3 76	1124		
F106P1.0Y	91	4.36	0.0142	2 3 76	1124		
F107P1.0Y	92	4.46	0.0194	8 10 76	904		
F108P1.0Y	91	2.52	0.0146	16 12 76	835		
M109P1.0Y	90	3.78	0.0155	9 3 78	387		
M110P1.0Y	88	3.77	0.0158	23 5 78	312		
F501P1.0+	1787	9.54	0.0158	10 6 75	1390		
F502P1.0+	1830	11.4	0.0174	6 7 77	633		
F503P1.0+	1855	9.76	0.0163	9 5 78	326		
M507P1.0+	1481	13.3	0.0158	9 5 78	326		
M001P1.7	657	8.72	0.0475	26 6 56		3025	151
F002P1.7	527	8.62	0.0431	22 11 55		3430	150
M003P1.7	642	8.63	0.0495	26 6 56		3430	173
M004P1.7	673	8.37	0.0484	10 10 56		3312	165
F005P1.7	642	11.6	0.0493	26 6 56		2659	142
F006P1.7	642	10.3	0.0459	26 6 56		2221	116
F007P1.7	756	9.73	0.0481	10 10 56		3353	165
M008P1.7	673	13.6	0.0479	10 10 56		3282	162
F009P1.7	756	9.72	0.0485	10 10 56		2500	134
F010P1.7	739	10.6	0.0495	10 10 56		467	36
F010P1.7A	472	8.07	0.0457	3 9 58		4214	187
M011P1.7	599	11.6	0.0486	24 4 56		2777	145
M012P1.7	673	9.41	0.0491	10 10 56		2973	154
M013P1.7	504	10.60	0.0473	3 9 58		4375	200

B. PLUTONIUM - 239 *

DOG NUMBER	COMMENTS ON DEAD DOGS
MO13P1.O	SENILITY, HYDROCEPHALUS
FO14P1.O	
MO15P1.O	
MO16P1.O	
MO17P1.O	
FO18P1.O	
MO19P1.O	
FO2OP1.O	TRANSITIONAL CELL CARCINOMA
MO21P1.O	
FO22P1.O	
FO23P1.O	
FO24P1.O	OSTEOSARCOMA; EMPYEMA
MO25P1.O	
F1O1P1.OY	
M1O2P1.OY	
F1O3P1.OY	
M1O4P1.OY	
M1O5P1.OY	
F1O6P1.OY	
F1O7P1.OY	
F1O8P1.OY	
M1O9P1.OY	
M11OP1.OY	
F5O1P1.O+	
F5O2P1.O+	
F5O3P1.O+	
M5O7P1.O+	
MOO1P1.7	OSTEOSARCOMA
FOO2P1.7	OSTEOSARCOMA
MOO3P1.7	CHROMOPHOBE ADENOMA OF PITUITARY, PROSTATE CARCINOMA
MOO4P1.7	OSTEOSARCOMA
FOO5P1.7	OSTEOSARCOMA
FOO6P1.7	OSTEOSARCOMA
FOO7P1.7	OSTEOSARCOMA
MOO8P1.7	OSTEOSARCOMA
FOO9P1.7	OSTEOSARCOMA
FO1OP1.7	ACUTE ENTERITIS
FO1OP1.7A	OSTEOSARCOMA
MO11P1.7	BILE DUCT CARCINOMA
MO12P1.7	LEUKEMIA
MO13P1.7	CHONDROSARCOMA (PROXIMAL HUMERUS)

B. PLUTONIUM - 239 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
F101P1.7Y	93	2.34	0.0543	19	9	74	1654		
M102P1.7Y	91	2.97	0.0545	19	9	74	1654		
F103P1.7Y	89	3.84	0.0453	21	11	74	1591		
M104P1.7Y	93	3.40	0.0488	27	4	76	1068		
M105P1.7Y	90	4.06	0.0485	27	4	76	1068		
F106P1.7Y	89	4.20	0.0529	26	11	74	1586		
F107P1.7Y	93	3.91	0.0477	24	9	76	918		
M108P1.7Y	92	4.32	0.0473	8	10	76	904		
F109P1.7Y	88	3.06	0.0510	20	4	78	345		
M110P1.7Y	92	3.07	0.0464	11	7	78	263		
F111P1.7Y	92	3.02	0.0471	11	7	78	263		
F501P1.7+	1725	10.0	0.0456	24	6	75	1376		
F502P1.7+	1732	10.0	0.0416	16	12	75	1201		
F503P1.7+	1826	10.2	0.0519	13	5	76	1052		
F504P1.7+	1831	11.2	0.0527	6	7	77	633		
F505P1.7+	1846	9.96	0.0441	9	5	78	326		
F506P1.7+	1823	9.56	0.0449	9	5	78	326		
M507P1.7+	1849	10.7	0.0458	20	7	78	254		
M508P1.7+	1840	12.6	0.0430	7	9	78	205		
M509P1.7+	1845	12.7	0.0498	30	11	78	121		
M510P1.7+	1835	11.5	0.0503	30	11	78	121		
M001P2.0	443	7.61	0.0853	1	12	52		2985	268
F002P2.0	422	7.73	0.112	2	3	53		2780	334
M003P2.0	485	10.5	0.0940	1	6	53		3185	310
M004P2.0	608	9.84	0.0862	16	9	53		2948	268
F005P2.0	594	8.12	0.0846	14	10	53		2423	228
F006P2.0	417	7.54	0.0902	12	5	54		2947	281
F007P2.0	485	8.40	0.0996	25	10	54		2093	240
M008P2.0	406	9.73	0.0957	15	3	55		1761	203
F009P2.0	552	9.72	0.101	9	9	55		2014	237
F010P2.0	551	7.94	0.0968	22	11	55		2912	299
M011P2.0	599	10.3	0.0961	24	4	56		1617	191
M012P2.0	622	9.98	0.100	29	5	56		2284	258
F101P2.0Y	91	2.60	0.0981	19	9	74	1654		
M102P2.0Y	91	2.85	0.106	19	9	74	1654		
M103P2.0Y	93	4.27	0.0904	2	3	76	1124		
F104P2.0Y	92	3.12	0.0904	13	4	76	1082		
M105P2.0Y	90	4.10	0.0963	27	4	76	1068		
F106P2.0Y	91	2.81	0.0961	27	4	76	1068		
F107P2.0Y	94	3.22	0.0980	22	9	76	920		
M108P2.0Y	91	3.69	0.0834	16	12	76	835		

B. PLUTONIUM - 239 *

DOG NUMBER	COMMENTS ON DEAD DOGS
F101P1.7Y	
M102P1.7Y	
F103P1.7Y	
M104P1.7Y	
M105P1.7Y	
F106P1.7Y	
F107P1.7Y	
M108P1.7Y	
F109P1.7Y	
M110P1.7Y	
F111P1.7Y	
F501P1.7+	
F502P1.7+	
F503P1.7+	
F504P1.7+	
F505P1.7+	
F506P1.7+	
M507P1.7+	
M508P1.7+	
M509P1.7+	
M510P1.7+	
M001P2.0	OSTEOSARCOMA
F002P2.0	OSTEOSARCOMA
M003P2.0	OSTEOSARCOMA
M004P2.0	OSTEOSARCOMA
F005P2.0	OSTEOSARCOMA
F006P2.0	OSTEOSARCOMA
F007P2.0	SQUAMOUS CELL CARCINOMA (FRONTAL SINUS)
M008P2.0	ASPIRATION PNEUMONIA
F009P2.0	OSTEOSARCOMA
F010P2.0	OSTEOSARCOMA
M011P2.0	OSTEOSARCOMA
M012P2.0	OSTEOSARCOMA
F101P2.0Y	
M102P2.0Y	
M103P2.0Y	
F104P2.0Y	
M105P2.0Y	
F106P2.0Y	
F107P2.0Y	
M108P2.0Y	

B. PLUTONIUM - 239 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
F109P2.OY	88	2.60	0.0921	9	5	78	326		
M110P2.OY	92	3.28	0.0929	11	7	78	263		
F111P2.OY	92	3.18	0.0958	11	7	78	263		
F501P2.O+	1787	10.2	0.0903	10	6	75	1390		
F502P2.O+	1757	10.2	0.0908	5	3	76	1121		
F503P2.O+	1743	8.44	0.110	5	3	76	1121		
F504P2.O+	1874	8.87	0.0922	20	7	78	254		
F505P2.O+	1855	7.60	0.0942	20	7	78	254		
F506P2.O+	1887	7.95	0.0923	7	9	78	205		
M507P2.O+	1838	11.8	0.0911	20	7	78	254		
M508P2.O+	1817	7.91	0.0917	7	9	78	205		
M509P2.O+	1835	10.6	0.0979	30	11	78	121		
M510P2.O+	1794	12.0	0.0988	30	11	78	121		
M001P3.O	418	8.00	0.261	1	12	52		1476	579
F002P3.O	422	6.85	0.312	2	3	53		1947	886
M003P3.O	485	8.74	0.291	1	6	53		1604	695
M004P3.O	608	8.51	0.292	16	9	53		1950	830
F005P3.O	650	8.22	0.288	14	10	53		1504	650
F006P3.O	415	8.38	0.282	12	5	54		1617	678
F007P3.O	485	9.00	0.314	25	10	54		1627	760
M008P3.O	406	9.73	0.300	15	3	55		1770	782
F009P3.O	552	7.67	0.300	9	9	55		1894	831
F010P3.O	533	8.94	0.298	22	11	55		1547	689
M011P3.O	599	10.5	0.309	24	4	56		1198	569
M012P3.O	622	10.2	0.308	29	5	56		1659	758
M081P3.OY	91	4.03	0.320	25	4	72	2531		
M086P3.OY	89	3.29	0.319	25	4	72	2531		
M089P3.OY	89	4.23	0.312	25	4	72	2531		
F101P3.OY	91	2.88	0.332	19	9	74	1654		
M102P3.OY	93	3.93	0.316	27	4	76	1068		
F103P3.OY	92	3.54	0.269	13	4	76	1082		
M104P3.OY	92	4.65	0.317	27	4	76	1068		
M105P3.OY	91	3.86	0.312	27	4	76	1068		
F106P3.OY	91	4.22	0.315	1	6	76	1033		
F107P3.OY	93	3.69	0.295	24	9	76	918		
M108P3.OY	90	3.56	0.283	16	12	76	835		
F109P3.OY	88	2.78	0.300	9	5	78	326		
F501P3.O+	1718	10.3	0.290	17	6	75	1383		
F502P3.O+	1739	9.56	0.298	23	12	75	1194		
F503P3.O+	1887	10.9	0.273	7	9	78	205		
F504P3.O+	1845	9.09	0.318	30	11	78	121		

B. PLUTONIUM - 239 *

DOG NUMBER	COMMENTS ON DEAD DOGS
F109P2.0Y	
M110P2.0Y	
F111P2.0Y	
F501P2.0+	
F502P2.0+	
F503P2.0+	
F504P2.0+	
F505P2.0+	
F506P2.0+	
M507P2.0+	
M508P2.0+	
M509P2.0+	
M510P2.0+	
M001P3.0	OSTEOSARCOMA
F002P3.0	OSTEOSARCOMA
M003P3.0	OSTEOSARCOMA
M004P3.0	OSTEOSARCOMA
F005P3.0	OSTEOSARCOMA
F006P3.0	OSTEOSARCOMA
F007P3.0	OSTEOSARCOMA
M008P3.0	OSTEOSARCOMA
F009P3.0	OSTEOSARCOMA
F010P3.0	OSTEOSARCOMA
M011P3.0	OSTEOSARCOMA
M012P3.0	OSTEOSARCOMA
M081P3.0Y	
M086P3.0Y	
M089P3.0Y	
F101P3.0Y	
M102P3.0Y	
F103P3.0Y	
M104P3.0Y	
M105P3.0Y	
F106P3.0Y	
F107P3.0Y	
M108P3.0Y	
F109P3.0Y	
F501P3.0+	
F502P3.0+	
F503P3.0+	
F504P3.0+	

B. PLUTONIUM - 239 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
F505P3.0+	1835	8.19	0.312	30 11 78	121		
F506P3.0+	1823	7.55	0.274	7 9 78	205		
M507P3.0+	1853	11.8	0.274	7 9 78	205		
M508P3.0+	1829	10.2	0.304	2 11 78	149		
M509P3.0+	1827	11.6	0.306	2 11 78	149		
M510P3.0+	1794	11.1	0.313	30 11 78	121		
M001P4.0	443	7.61	0.823	1 12 52		1724	2215
F002P4.0	568	8.65	1.03	2 3 53		1556	2521
M003P4.0	485	9.36	0.929	1 6 53		1198	1784
M004P4.0	566	8.74	0.974	16 9 53		1066	1678
F005P4.0	650	7.05	0.872	14 10 53		1245	1736
F006P4.0	420	9.26	0.811	12 5 54		1357	1749
F007P4.0	485	8.45	0.963	25 10 54		1198	1850
M008P4.0	651	9.22	0.887	15 3 55		1157	1650
F009P4.0	552	8.58	0.960	9 9 55		1343	2050
F010P4.0	527	6.48	0.868	22 11 55		1241	1723
M011P4.0	596	9.56	0.927	24 4 56		1288	1904
M012P4.0	598	11.4	0.838	29 5 56		1463	1938
M001P5.0	418	8.86	2.67	1 12 52		1324	5873
F002P5.0	1151	8.75	3.30	2 3 53		1576	8575
M003P5.0	515	8.10	3.00	1 6 53		499	2577
M004P5.0	566	9.18	3.17	16 9 53		1562	8167
F005P5.0	691	8.77	2.77	14 10 53		2059	9292
F006P5.0	407	7.90	2.57	12 5 54		1194	5121
F007P5.0	482	8.33	2.99	25 10 54		1491	7368
M008P5.0	497	9.55	2.69	15 3 55		1192	5351
F009P5.0	552	9.45	2.73	9 9 55		1145	5226
M081P5.0Y	94	4.60	2.68	1 3 72		1161	2503
F082P5.0Y	94	4.80	2.66	1 3 72		1295	3280
F083P5.0Y	94	4.00	2.66	1 3 72		1442	3862
F084P5.0Y	94	3.55	2.68	1 3 72		1259	2727
F085P5.0Y	94	4.15	2.64	1 3 72		1134	2503
M086P5.0Y	93	3.75	2.95	25 4 72		1345	2792
F087P5.0Y	93	4.15	2.93	25 4 72		1119	3095
F088P5.0Y	93	3.65	2.96	25 4 72		1227	2562
M089P5.0Y	93	3.79	2.92	25 4 72		1443	2432
M090P5.0Y	93	4.38	2.97	25 4 72		1137	2512
M091P5.0Y	91	3.78	2.90	25 4 72		1491	2619
M092P5.0Y	91	3.82	2.87	25 4 72		1616	3307

*

F502P2+ and F503P2+ were given tracer (~0.24 uCi) 237Pu in the same injection solution containing their 239Pu.

B. PLUTONIUM - 239 *

DOG NUMBER	COMMENTS ON DEAD DOGS
F505P3.0+	
F506P3.0+	
M507P3.0+	
M508P3.0+	
M509P3.0+	
M510P3.0+	
M001P4.0	OSTEOSARCOMA
F002P4.0	OSTEOSARCOMA
M003P4.0	OSTEOSARCOMA
M004P4.0	OSTEOSARCOMA
F005P4.0	OSTEOSARCOMA
F006P4.0	OSTEOSARCOMA
F007P4.0	OSTEOSARCOMA
M008P4.0	OSTEOSARCOMA
F009P4.0	OSTEOSARCOMA
F010P4.0	OSTEOSARCOMA
M011P4.0	OSTEOSARCOMA
M012P4.0	OSTEOSARCOMA
M001P5.0	OSTEOSARCOMA
F002P5.0	OSTEOSARCOMA + FRACTURED MANDIBLE
M003P5.0	LIVER DEGENERATION + ASCITES
M004P5.0	OSTEOSARCOMA
F005P5.0	OSTEOSARCOMA, LIVER DEGENERATION + HEPATIC HEMORRHAGE
F006P5.0	OSTEOSARCOMA
F007P5.0	OSTEOSARCOMA + CRIPPLING FRACTURE
M008P5.0	GINGIVITIS
F009P5.0	OSTEOSARCOMA, EPISTAXIS + CIRCULATORY COLLAPSE
M081P5.0Y	OSTEOSARCOMA
F082P5.0Y	OSTEOSARCOMA
F083P5.0Y	OSTEOSARCOMA; FIBROSARCOMA (SOFT TISSUE)
F084P5.0Y	OSTEOSARCOMA
F085P5.0Y	OSTEOSARCOMA
M086P5.0Y	OSTEOSARCOMA
F087P5.0Y	OSTEOSARCOMA
F088P5.0Y	OSTEOSARCOMA
M089P5.0Y	OSTEOSARCOMA
M090P5.0Y	OSTEOSARCOMA
M091P5.0Y	OSTEOSARCOMA
M092P5.0Y	OSTEOSARCOMA

C. RADIUM - 228 (MESOTHORIUM) *

DOG NUMBER	INJECTION AGE (DAYS)	INJECTION WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
FO01MO.0	732	7.33		4	1	54		3451	
FO02MO.0	545	6.94		29	11	54		6155	
MO03MO.0	579	13.0		13	3	56		5056	
MO04MO.0	601	10.3		15	1	57		4816	
FO05MO.0	671	11.2		5	3	57		4581	
MO06MO.0	492	7.56		23	4	57		4934	
FO07MO.0	395	8.71		4	6	57		1414	
FO07MO.0A	594	10.9		15	1	63		3624	
FO08MO.0	654	11.6		9	3	60		5009	
MO09MO.0	575	12.4		13	4	60		4130	
MO10MO.0	581	13.3		17	7	62		2991	
FO11MO.0	475	9.31		18	9	62		3248	
MO12MO.0	695	10.0		22	12	60		4810	
FO01MO.5	492	9.47	0.0173	17	7	62		5460	92
FO02MO.5	492	9.15	0.0173	17	7	62		3689	124
MO03MO.5	493	10.8	0.0199	18	9	62		4697	147
MO04MO.5	475	12.8	0.0199	18	9	62		4193	159
FO05MO.5	534	7.83	0.0172	23	10	62		3958	107
MO06MO.5	510	10.3	0.0171	23	10	62		3019	95
FO07MO.5	492	8.87	0.0172	17	7	62		4997	148
FO08MO.5	654	12.6	0.0159	9	3	60		4208	93
MO09MO.5	485	11.9	0.0170	13	4	60		5321	141
MO10MO.5	492	10.6	0.0174	17	7	62		4567	147
FO11MO.5	505	7.82	0.0202	18	9	62		4033	140
MO12MO.5	510	10.6	0.0165	23	10	62		3920	111
FO01M1.0	718	7.75	0.0463	4	1	54		2950	261
FO01M1.0A	590	8.07	0.0512	23	10	62		4292	292
FO02M1.0	459	8.25	0.0324	29	11	54		5267	284
MO03M1.0	575	13.8	0.0589	13	3	56		3157	408
MO04M1.0	601	9.90	0.0481	15	1	57		4260	175
FO05M1.0	658	8.80	0.0490	5	3	57		4565	256
MO06M1.0	521	10.6	0.0468	23	4	57		3402	363
FO07M1.0	534	9.89	0.0489	4	6	57		2159	199
FO08M1.0	654	12.4	0.0491	9	3	60		3886	320
MO09M1.0	485	10.1	0.0504	13	4	60		4670	429
MO10M1.0	492	9.43	0.0501	17	7	62		2966	284
FO11M1.0	505	8.91	0.0613	18	9	62		4943	536
MO12M1.0	528	9.27	0.0498	23	10	62		3786	308

C. RADIUM - 228 (MESOTHORIUM) *

DOG NUMBER	COMMENTS ON DEAD DOGS
F001M0.0	PURULENT MENINGOENCEPHALITIS
F002M0.0	UNDETERMINED; SENILITY
M003M0.0	BRAIN INFARCTION
M004M0.0	VALVULAR ENDOCARDITIS; MYOCARDIAL INFARCTION
F005M0.0	MAMMARY CARCINOMA
M006M0.0	NEPHRITIS
F007M0.0	STATUS EPILEPTICUS
F007M0.0A	PNEUMONIA
F008M0.0	AORTIC THROMBOEMBOLISM
M009M0.0	VIRUS PNEUMONIA
M010M0.0	MALIGNANT MELANOMA (ORAL)
F011M0.0	ASPIRATION PNEUMONIA
M012M0.0	PULMONARY THROMBOEMBOLISM; TRANSITIONAL CELL CARCINOMA
F001M0.5	THROMBO-EMBOLISM PORTAL VEIN
F002M0.5	CHRONIC PANCREATITIS
M003M0.5	AORTIC THROMBO-EMBOLISM
M004M0.5	UNDIFFERENTIATED SARCOMA (NON-SKELETAL)
F005M0.5	UNDETERMINED (NO BONE TUMOR)
M006M0.5	MALIGNANT MELANOMA (EYE)
F007M0.5	PNEUMONIA; MELANOMA (EYE)
F008M0.5	BACTERIAL ENTERITIS
M009M0.5	AORTA THROMBO-EMBOLISM
M010M0.5	KIDNEY DEGENERATION; AORTA THROMBOEMBOLISM
F011M0.5	BILE DUCT OBSTRUCTION; EYE MELANOMA
M012M0.5	STATUS EPILEPTICUS
F001M1.0	SARCOMA (SPLEEN)
F001M1.0A	KIDNEY DEGENERATION
F002M1.0	OSTEOSARCOMA
M003M1.0	OSTEOSARCOMA
M004M1.0	PNEUMONIA; PANCREATITIS
F005M1.0	MALIGNANT MELANOMA (EYE)
M006M1.0	EPIDERMOID CARCINOMA (PENIS)
F007M1.0	SARCOMA (HEART)
F008M1.0	MALIGNANT MELANOMA (EYE)
M009M1.0	VALVULAR ENDOCARDITIS
M010M1.0	MALIGNANT MELANOMA (EYE)
F011M1.0	MAMMARY CARCINOMA
M012M1.0	LYMPHATIC LEUKEMIA

C. RADIUM - 228 (MESOTHORIUM) *

DOG NUMBER	INJECTION AGE (DAYS)	INJECTION WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79 DEATH	DOSE TO SKELETON (RADS)
FO01M1.7	510	7.52	0.151	23 10 62	4265	956
FO02M1.7	560	9.90	0.183	13 3 56	2383	977
MO03M1.7	576	11.0	0.180	13 3 56	2709	964
MO04M1.7	601	8.94	0.143	15 1 57	2864	565
FO05M1.7	658	12.8	0.141	5 3 57	3234	833
MO06M1.7	521	10.0	0.144	23 4 57	3424	524
FO07M1.7	534	10.2	0.146	4 6 57	2646	800
FO08M1.7	654	10.8	0.148	9 3 60	2486	515
MO09M1.7	485	12.6	0.149	13 4 60	2799	896
MO10M1.7	492	10.1	0.124	17 7 62	3101	997
FO11M1.7	505	10.7	0.179	18 9 62	3325	1347
MO12M1.7	524	9.28	0.153	23 10 62	3017	957
FO01M2.0	676	7.60	0.276	4 1 54	1780	1160
FO02M2.0	517	8.25	0.194	29 11 54	965	264
MO03M2.0	576	11.0	0.358	13 3 56	619	473
MO04M2.0	601	9.88	0.282	15 1 57	2282	1377
FO05M2.0	509	8.30	0.295	5 3 57	2688	1237
MO06M2.0	502	12.4	0.306	23 4 57	2674	1843
FO07M2.0	534	10.1	0.298	4 6 57	2239	1419
FO08M2.0	654	12.4	0.300	9 3 60	2386	1237
MO09M2.0	630	9.99	0.302	13 4 60	1254	748
MO10M2.0	430	11.2	0.311	17 7 62	2373	1931
FO11M2.0	505	7.03	0.381	18 9 62	2878	1461
MO12M2.0	524	9.47	0.306	23 10 62	2471	1992
FO01M3.0	519	10.4	0.858	4 1 54	918	2444
FO02M3.0	460	6.70	0.612	29 11 54	1856	2767
MO03M3.0	579	10.4	0.965	13 3 56	1185	3285
MO04M3.0	601	10.2	0.916	15 1 57	1176	2123
FO05M3.0	531	8.51	0.940	5 3 57	1869	2864
MO06M3.0	502	9.09	0.953	23 4 57	1421	2541
FO07M3.0	534	9.94	0.907	4 6 57	1463	4193
FO08M3.0	633	11.8	0.950	9 3 60	1447	2877
MO09M3.0	630	9.83	0.918	13 4 60	1570	3036
MO10M3.0	581	10.4	1.00	17 7 62	1575	3091
FO11M3.0	499	11.0	1.19	18 9 62	1395	3289
MO12M3.0	510	12.9	0.987	23 10 62	1638	3153
FO01M4.0	510	7.56	2.60	4 1 54	841	7485
FO02M4.0	460	6.95	1.86	29 11 54	770	3029

C. RADIUM - 228 (MESOTHORIUM) *

DOG NUMBER	COMMENTS ON DEAD DOGS
FOO1M1.7	OSTEOSARCOMA
FOO2M1.7	OSTEOSARCOMA
MOO3M1.7	OSTEOSARCOMA
MOO4M1.7	CARCINOMA SMALL INTESTINE
FOO5M1.7	OSTEOSARCOMA
MOO6M1.7	OSTEOSARCOMA
FOO7M1.7	OSTEOSARCOMA
FOO8M1.7	OSTEOSARCOMA
MOO9M1.7	OSTEOSARCOMA
MO1OM1.7	OSTEOSARCOMA
FO11M1.7	OSTEOSARCOMA
MO12M1.7	UNKNOWN (NO BONE TUMOR)
FOO1M2.O	OSTEOSARCOMA
FOO2M2.O	INTESTINAL HEMORRHAGE
MOO3M2.O	PNEUMONIA
MOO4M2.O	OSTEOSARCOMA
FOO5M2.O	OSTEOSARCOMA
MOO6M2.O	OSTEOSARCOMA
FOO7M2.O	CHRONIC PANCREATITIS
FOO8M2.O	OSTEOSARCOMA
MOO9M2.O	OSTEOSARCOMA
MO1OM2.O	OSTEOSARCOMA
FO11M2.O	OSTEOSARCOMA
MO12M2.O	OSTEOSARCOMA
FOO1M3.O	OSTEOSARCOMA
FOO2M3.O	OSTEOSARCOMA
MOO3M3.O	OSTEOSARCOMA
MOO4M3.O	OSTEOSARCOMA
FOO5M3.O	OSTEOSARCOMA
MOO6M3.O	OSTEOSARCOMA
FOO7M3.O	OSTEOSARCOMA
FOO8M3.O	OSTEOSARCOMA
MOO9M3.O	OSTEOSARCOMA
MO1OM3.O	OSTEOSARCOMA
FO11M3.O	OSTEOSARCOMA
MO12M3.O	OSTEOSARCOMA
FOO1M4.O	OSTEOSARCOMA + CRIPPLING FRACTURE
FOO2M4.O	OSTEOSARCOMA

C. RADIUM - 228 (MESOTHORIUM) *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
MOO3M4.O	579	9.65	3.37	13	3	56		418	2393
MOO3M4.OA	494	7.34	2.64	4	6	57		1063	7472
MOO4M4.O	609	7.84	2.47	15	1	57		896	3573
FOO5M4.O	509	9.63	2.67	5	3	57		1064	5811
MOO6M4.O	502	9.49	2.66	23	4	57		1121	6379
FOO7M4.O	544	8.40	2.67	4	6	57		1253	6181
FOO1M5.O	494	7.77	8.11	4	1	54		232	5139
FOO2M5.O	460	7.35	5.46	29	11	54		780	10221
MOO3M5.O	579	8.87	10.4	13	3	56		688	18868
MOO4M5.O	482	7.29	7.89	15	1	57		561	7549
FOO5M5.O	658	11.1	8.48	5	3	57		770	12745
MOO6M5.O	580	7.53	8.67	23	4	57		792	9015
FOO7M5.O	494	7.35	8.92	4	6	57		966	24125

*

(uCi 228Th/uCi 228Ra) injected = 0.15 for F1M1.0, 2.0, 3.0, 4.0, 5.0.

= 0.03 for F2M1.0, 1.7, 2.0, 3.0, 4.0, 5.0.
M3M1.0, 1.7, 2.0, 3.0, 4.0, 5.0.

= 0.006 for groups 4, 5, 6, 7, 8, 9, 10, 11, 12
and dogs F1MO.5, F2MO.5, M3MO.5,
F1M1A, F1M1.7, M3M4.OA

C. RADIUM - 228 (MESOTHORIUM) *

DOG NUMBER	COMMENTS ON DEAD DOGS
MOO3M4.O	STRANGULATED INGUINAL HERNIA
MOO3M4.OA	OSTEOSARCOMA, NEPHRITIS, ULCERATIVE GINGIVITIS + PNEUMONIA
MOO4M4.O	FRACTURED MANDIBLE + ULCERATIVE GINGIVITIS
FOO5M4.O	OSTEOSARCOMA
MOO6M4.O	OSTEOSARCOMA
FOO7M4.O	OSTEOSARCOMA
FOOlM5.O	NEPHRITIS + SEVERE ANEMIA
FOO2M5.O	CRIPPLING FRACTURES
MOO3M5.O	ULCERATIVE GINGIVITIS
MOO4M5.O	CRIPPLING FRACTURE
FOO5M5.O	ULCERATIVE GINGIVITIS
MOO6M5.O	OSTEOSARCOMA +CRIPPLING FRACTURE
FOO7M5.O	ULCERATIVE GINGIVITIS, MYOCARDIAL INFARCTION + GLAUCOMA

D. THORIUM - 228 (RADIOTHORIUM)

DOG NUMBER	INJECTION AGE (DAYS)	INJECTION WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
MO01TO.0	493	8.24		8	2	54		4895	
MO02TO.0	488	7.28		28	9	54		5510	
FO03TO.0	797	11.6		6	6	55		2592	
MO04TO.0	591	8.10		18	10	55		3072	
MO05TO.0	458	10.4		14	10	58		5306	
FO06TO.0	489	9.64		10	1	61		171	
FO06TO.0A	688	8.61		15	12	60		4549	
MO07TO.0	517	10.5		7	2	61		1412	
MO08TO.0	533	10.8		24	5	61		4963	
FO09TO.0	569	8.28		29	6	61		5061	
FO10TO.0	536	10.4		28	7	61		4700	
FO11TO.0	530	9.45		4	6	63		4271	
FO12TO.0	492	9.09		9	7	63		4137	
MO01TO.2	682	11.4	0.00164	27	3	62		4837	20
MO02TO.2	682	10.4	0.00166	27	3	62		4822	20
FO03TO.2	478	9.86	0.00163	27	3	62		4720	20
MO04TO.2	478	10.0	0.00166	27	3	62		4515	20
MO05TO.2	625	13.8	0.00162	9	2	60		889	13
MO05TO.2A	530	13.4	0.00173	4	6	63		5609	21
FO06TO.2	489	8.85	0.00176	10	1	61		4767	18
MO07TO.2	532	10.5	0.00159	7	2	61		3897	20
MO08TO.2	494	13.9	0.00189	24	5	61		4826	23
FO09TO.2	569	7.82	0.00171	29	6	61		3897	21
FO10TO.2	508	10.5	0.00170	28	7	61		4217	21
FO11TO.2	530	9.76	0.00171	4	6	63		4573	21
FO12TO.2	492	7.37	0.00190	9	7	63		3350	23
MO01TO.5	699	14.3	0.00496	7	9	56		3471	60
MO02TO.5	455	10.5	0.00490	28	9	54		1976	55
FO03TO.5	659	8.59	0.00485	6	6	55		3032	59
MO04TO.5	516	8.58	0.00540	18	10	55		2159	61
MO05TO.5	513	8.46	0.00522	14	10	58		4856	67
FO06TO.5	489	9.66	0.00510	10	1	61		4518	63
MO07TO.5	532	9.11	0.00491	7	2	61		5840	53
MO08TO.5	533	9.53	0.00562	24	5	61		4599	69
FO09TO.5	569	8.62	0.00529	29	6	61		4149	65
FO10TO.5	508	10.2	0.00510	28	7	61		4947	63
FO11TO.5	530	7.78	0.00518	4	6	63		3952	63
FO12TO.5	492	9.94	0.00567	9	7	63		1682	60

D. THORIUM - 228 (RADIOTHORIUM)

DOG NUMBER	COMMENTS ON DEAD DOGS
M001TO.0	RETICULUM CELL SARCOMA (SOFT TISSUE)
M002TO.0	NEPHROSIS
F003TO.0	BRAIN HEMORRHAGE
M004TO.0	LYMPHOSARCOMA
M005TO.0	LYMPHOSARCOMA
F006TO.0	TRAUMA
F006TO.0A	PERICARDITIS
M007TO.0	BRAIN HEMORRHAGE
M008TO.0	UNDETERMINED (NO BONE TUMOR)
F009TO.0	TRANSITIONAL CELL CARCINOMA
F010TO.0	AORTIC BODY TUMOR
F011TO.0	STATUS EPILEPTICUS
F012TO.0	TRANSITIONAL CELL CARCINOMA
M001TO.2	LUNG CARCINOMA
M002TO.2	MELANOMA (ORAL); GASTRIC CARCINOMA
F003TO.2	STATUS EPILEPTICUS
M004TO.2	TRANSITIONAL CELL CARCINOMA; AORTA THROMBOEMBOLISM
M005TO.2	STRANGULATION ON VOMITUS + GRAND MAL
M005TO.2A	SENILITY
F006TO.2	ISLET CELL TUMOR
M007TO.2	UNDIFFERENTIATED MALIGNANCY (INTESTINE)
M008TO.2	LEIOMYOSARCOMA
F009TO.2	PULMONARY THROMBO EMBOLISM
F010TO.2	BILE DUCT OBSTRUCTION; MAMMARY CARCINOMA
F011TO.2	BILE DUCT OBSTRUCTION, ISLET CELL CARCINOMA
F012TO.2	HEPATIC CELL CARCINOMA
M001TO.5	CEREBRAL INFARCTION HEMORRHAGE
M002TO.5	STRANGULATION ON VOMITUS + GRAND MAL
F003TO.5	PYOMETRITIS + SECONDARY PERITONITIS
M004TO.5	STATUS EPILEPTICUS + PNEUMONIA
M005TO.5	PROSTATITIS
F006TO.5	ISLET CELL TUMOR
M007TO.5	NEPHRITIS; PROSTATE CARCINOMA
M008TO.5	OSTEOSARCOMA
F009TO.5	MAMMARY CARCINOMA
F010TO.5	OSTEOSARCOMA; THYROID CARCINOMA
F011TO.5	PULMONARY THROMBOEMBOLISM
F012TO.5	LIVER DEGENERATION, ANESTHETIC REACTION

D. THORIUM - 228 (RADIOTHORIUM)

DOG NUMBER	INJECTION AGE (DAYS)	INJECTION WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
MO01T1.0	493	9.36	0.0146	8	2	54		3172	176
MO02T1.0	699	9.27	0.0146	7	9	56		4570	180
FO03T1.0	723	8.84	0.0145	7	9	56		4142	177
MO04T1.0	699	8.27	0.0146	7	9	56		3217	176
MO05T1.0	513	11.9	0.0146	14	10	58		2886	173
FO06T1.0	489	8.81	0.0150	10	1	61		3273	181
MO07T1.0	532	9.18	0.0147	7	2	61		3538	179
MO08T1.0	533	8.69	0.0166	24	5	61		5298	205
FO09T1.0	527	10.0	0.0160	29	6	61		2546	187
FO10T1.0	508	10.2	0.0150	28	7	61		3420	181
FO11T1.0	521	7.55	0.0154	4	6	63		4034	189
FO12T1.0	472	9.96	0.0167	9	7	63		1263	157
MO01T1.5	699	7.95	0.0289	7	9	56		2894	344
MO02T1.5	458	10.0	0.0293	28	9	54		2576	343
FO03T1.5	609	10.3	0.0303	6	6	55		1921	332
MO04T1.5	591	8.59	0.0299	18	10	55		2309	343
MO05T1.5	598	9.65	0.0286	9	2	60		1624	297
FO06T1.5	489	8.14	0.0292	10	1	61		2373	336
MO07T1.5	517	8.83	0.0292	7	2	61		380	127
MO07T1.5A	521	9.08	0.0311	4	6	63		3110	373
MO08T1.5	494	11.6	0.0324	24	5	61		2665	381
FO09T1.5	527	8.80	0.0306	29	6	61		2983	365
FO10T1.5	508	11.6	0.0296	28	7	61		1859	321
FO11T1.5	518	11.4	0.0305	4	6	63		2408	375
FO12T1.5	465	7.56	0.0329	9	7	63		2120	371
MO01T2.0	491	10.2	0.0976	8	2	54		1282	924
MO02T2.0	483	9.16	0.0875	28	9	54		1234	815
FO03T2.0	474	7.87	0.0908	6	6	55		1541	927
MO04T2.0	553	13.0	0.0900	18	10	55		78	93
MO04T2.0A	650	10.6	0.0899	7	9	56		1222	833
MO05T2.0	598	9.12	0.0848	9	2	60		1085	741
FO06T2.0	451	8.65	0.0879	10	1	61		1108	777
MO07T2.0	517	8.85	0.0881	7	2	61		1015	744
MO08T2.0	533	10.7	0.0981	24	5	61		1078	855
FO09T2.0	527	8.09	0.0979	29	6	61		1209	903
FO10T2.0	508	10.7	0.0919	28	7	61		1022	779
FO11T2.0	518	10.8	0.0904	4	6	63		1038	772
FO12T2.0	464	8.92	0.100	9	7	63		1449	997

D. THORIUM - 228 (RADIOTHORIUM)

DOG NUMBER	COMMENTS ON DEAD DOGS
M001T1.0	OSTEOSARCOMA
M002T1.0	PERIANAL GLAND ADENOMA
F003T1.0	UNDIFFERENTIATED MALIGNANCY (SOFT TISSUE)
M004T1.0	OSTEOSARCOMA THYROID CARCINOMA PERIANAL ADENOCARCINOMA
M005T1.0	STATUS EPILEPTICUS
F006T1.0	STOMACH PERFORATION
M007T1.0	OSTEOSARCOMA
M008T1.0	LUNG CARCINOMA; NEPHRITIS
F009T1.0	LEIOMYOSARCOMA
F010T1.0	OSTEOSARCOMA
F011T1.0	OSTEOSARCOMA
F012T1.0	PNEUMONIA
M001T1.5	OSTEOSARCOMA
M002T1.5	OSTEOSARCOMA
F003T1.5	COMA OF UNKNOWN ETIOLOGY (NO BONE TUMOR)
M004T1.5	OSTEOSARCOMA
M005T1.5	OSTEOSARCOMA
F006T1.5	OSTEOSARCOMA
M007T1.5	LEPTOSPIROSIS
M007T1.5A	OSTEOSARCOMA; (PNEUMONIA)
M008T1.5	OSTEOSARCOMA
F009T1.5	OSTEOSARCOMA
F010T1.5	OSTEOSARCOMA
F011T1.5	OSTEOSARCOMA
F012T1.5	OSTEOSARCOMA
M001T2.0	OSTEOSARCOMA
M002T2.0	OSTEOSARCOMA
F003T2.0	OSTEOSARCOMA
M004T2.0	TRAUMA
M004T2.0A	OSTEOSARCOMA
M005T2.0	OSTEOSARCOMA
F006T2.0	OSTEOSARCOMA
M007T2.0	OSTEOSARCOMA
M008T2.0	OSTEOSARCOMA
F009T2.0	OSTEOSARCOMA
F010T2.0	OSTEOSARCOMA
F011T2.0	OSTEOSARCOMA
F012T2.0	OSTEOSARCOMA

D. THORIUM - 228 (RADIOTHORIUM)

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
MO01T3.0	314	9.15	0.301	8	2	54		988	2505
MO02T3.0	458	11.9	0.301	28	9	54		859	2315
FO03T3.0	471	12.0	0.272	6	6	55		547	1552
MO04T3.0	606	9.69	0.285	18	10	55		801	2100
MO05T3.0	571	10.7	0.269	9	2	60		890	2112
FO06T3.0	451	8.83	0.282	10	1	61		1156	2545
MO07T3.0	427	9.90	0.266	7	2	61		861	2048
MO08T3.0	494	10.1	0.313	24	5	61		685	2088
FO09T3.0	511	11.5	0.298	29	6	61		1062	2577
FO10T3.0	508	9.26	0.280	28	7	61		971	2309
FO11T3.0	518	10.3	0.290	4	6	63		826	2121
FO12T3.0	459	11.5	0.320	9	7	63		804	2364
MO01T4.0	480	8.32	0.882	8	2	54		645	5649
MO02T4.0	458	8.32	0.916	28	9	54		833	6913
FO03T4.0	461	7.25	0.800	6	6	55		763	5720
MO04T4.0	606	8.81	0.835	18	10	55		793	6116
MO01T5.0	480	9.48	2.76	8	2	54		212	7276
MO02T5.0	483	8.22	2.63	28	9	54		97	3380

D. THORIUM - 228 (RADIOTHORIUM)

DOG NUMBER	COMMENTS ON DEAD DOGS
M001T3.0	OSTEOSARCOMA + SEVERE ANEMIA
M002T3.0	OSTEOSARCOMA + TRAUMA
F003T3.0	OSTEOSARCOMA
M004T3.0	OSTEOSARCOMA
M005T3.0	OSTEOSARCOMA
F006T3.0	OSTEOSARCOMA
M007T3.0	OSTEOSARCOMA
M008T3.0	OSTEOSARCOMA
F009T3.0	OSTEOSARCOMA
F010T3.0	OSTEOSARCOMA
F011T3.0	OSTEOSARCOMA
F012T3.0	HEMANGIOSARCOMA (HUMERUS)
M001T4.0	OSTEOSARCOMA + CRIPPLING FRACTURE
M002T4.0	OSTEOSARCOMA, CRIPPLING FRACTURE + NEPHRITIS
F003T4.0	ULCERATIVE GINGIVITIS + NEPHRITIS
M004T4.0	ULCERATIVE GINGIVITIS
M001T5.0	NEPHRITIS
M002T5.0	PANCYTOPENIA

E. STRONTIUM - 90

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
FOO1SO.O	502	8.48		18	1	55	5484		
MOO2SO.O	600	11.1		14	2	56	3838		
MOO3SO.O	493	9.03		11	9	57	3516		
FOO4SO.O	520	8.19		15	10	57	5755		
MOO5SO.O	542	10.6		19	11	57	4158		
MOO6SO.O	466	9.68		27	5	58	4726		
FOO7SO.OA	462	9.46		7	1	59	3303		
FOO8SO.O	483	9.29		19	5	59	4482		
FOO9SO.O	549	12.4		11	8	59	708		
FOO9SO.OA	535	11.2		4	6	63	3425		
MO1OSO.O	522	13.9		29	9	59	4977		
FO11SO.O	541	9.60		3	11	59	4831		
MO12SO.O	605	8.99		6	1	60	5374		
FOO1S1.O	1525	6.84	0.573	18	1	55	308		28
FOO1S1.OA	521	9.38	0.588	14	2	56	5219		90
MOO2S1.O	567	8.81	0.606	14	2	56	5077		120
MOO3S1.O	493	10.9	0.572	11	9	57	5363		189
FOO4S1.O	525	8.96	0.560	15	10	57	5902		198
MOO5S1.O	555	10.2	0.532	19	11	57	2705		95
MOO6S1.O	466	9.56	0.581	27	5	58	5739		292
FOO7S1.O	524	9.94	0.517	11	11	58	5837		161
FOO8S1.O	483	10.8	0.697	19	5	59	2783		105
FOO9S1.O	549	11.6	0.534	11	8	59	3601		116
MO1OS1.O	522	11.5	0.558	29	9	59	5321		144
FO11S1.O	543	10.3	0.550	3	11	59	4944		141
MO12S1.O	607	13.7	0.559	6	1	60	4184		133
FOO1S1.7	526	7.41	1.78	14	2	56	5624		627
MOO2S1.7	567	11.6	1.84	14	2	56	4297		540
MOO3S1.7	493	9.19	1.69	11	9	57	4846		451
FOO4S1.7	522	9.60	1.68	15	10	57	4628		372
MOO5S1.7	560	9.85	1.60	19	11	57	1715		220
MOO5S1.7A	493	11.4	1.78	6	3	63	5379		765
MOO6S1.7	466	10.6	1.72	27	5	58	5581		725
FOO7S1.7	488	10.2	1.60	11	11	58	3990		331
FOO8S1.7	472	8.47	2.03	19	5	59	1973		285
FOO9S1.7	549	10.0	1.62	11	8	59	4803		552
MO1OS1.7	519	13.6	1.66	29	9	59	2947		408
FO11S1.7	543	11.0	1.68	3	11	59	3180		319
MO12S1.7	607	11.9	1.68	6	1	60	4717		473

E. STRONTIUM - 90

DOG NUMBER	COMMENTS ON DEAD DOGS
F001S0.0	CARCINOMA PANCREAS
M002S0.0	LUNG CARCINOMA
M003S0.0	OBTURATING AORTIC EMBOLISM, NEPHRITIS
F004S0.0	NEPHRITIS; SENILITY
M005S0.0	TRANSITIONAL CELL CARCINOMA
M006S0.0	MELANOMA (ORAL)
F007S0.0A	DIABETES MELLITUS
F008S0.0	DIABETES MELLITUS
F009S0.0	TRAUMA
F009S0.0A	MAMMARY CARCINOMA
M010S0.0	FIBROSARCOMA (NON-SKELETAL)
F011S0.0	MAMMARY CARCINOMA
M012S0.0	INTESTINAL CARCINOMA; SENILITY
F001S1.0	SACRIFICED -IMPROPER INJECTION AGE-
F001S1.0A	PULMONARY THROMBO-EMBOLISM
M002S1.0	AORTIC BODY TUMOR
M003S1.0	SQUAMOUS CELL CARCINOMA (OROPHARNYX)
F004S1.0	NEPHRITIS; MAMMARY CARCINOMA
M005S1.0	STATUS EPILEPTICUS
M006S1.0	LYMPHOSARCOMA
F007S1.0	LYMPHOSARCOMA; MAMMARY CARCINOMA
F008S1.0	PANCREATIC ISLET CELL CARCINOMA
F009S1.0	FOREIGN BODY PNEUMONIA; ENTERITIS
M010S1.0	SEBACEOUS GLAND ADENOCARCINOMA
F011S1.0	TRANSITIONAL CELL CARCINOMA
M012S1.0	BILIARY OBSTRUCTION
F001S1.7	HEMANGIOENDOTHELIAL SARCOMA (LIVER)
M002S1.7	HEMANGIOSARCOMA (SOFT TISSUE ORIGIN)
M003S1.7	OBTURATING THROMBOEMBOLISM, AORTA
F004S1.7	PANCREATIC CARCINOMA
M005S1.7	COMA OF UNKNOWN ETIOLOGY (NO BONE TUMOR)
M005S1.7A	SENILITY
M006S1.7	TRANSITIONAL CELL CARCINOMA; HYDRONEPHROSIS
F007S1.7	ARTHRITIS; MAMMARY CARCINOMA
F008S1.7	STATUS EPILEPTICUS, CHRONIC PANCREATITIS
F009S1.7	LYMPHOSARCOMA; NEPHRITIS
M010S1.7	OBTURATING PULMONARY EMBOLISM, NEPHRITIS
F011S1.7	AORTIC THROMBUS; METASTATIC CALCIFICATION OF LUNGS
M012S1.7	ISLET CELL TUMOR

E. STRONTIUM - 90

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79 DEATH	DOSE TO SKELETON (RADS)
F001S2.0	502	5.59	3.70	18 1 55	3269	636
M002S2.0	567	8.97	3.42	14 2 56	3768	841
M003S2.0	494	7.82	3.39	11 9 57	4295	893
F004S2.0	522	9.68	3.41	15 10 57	4775	981
M005S2.0	560	8.72	3.24	19 11 57	3253	708
M006S2.0	466	9.19	3.50	27 5 58	5193	1131
F007S2.0	488	11.2	3.19	11 11 58	3421	609
F008S2.0	465	9.49	4.14	19 5 59	3955	913
F009S2.0	473	14.1	3.28	11 8 59	2467	755
M010S2.0	508	10.7	3.34	29 9 59	3430	791
F011S2.0	543	10.4	3.41	3 11 59	4880	879
M012S2.0	607	11.6	3.49	6 1 60	4584	943
F001S3.0	468	7.36	11.6	18 1 55	5149	4385
M002S3.0	565	9.62	11.6	14 2 56	4263	3473
M003S3.0	494	11.4	10.8	11 9 57	4947	3197
F004S3.0	527	9.17	10.6	15 10 57	3101	1987
M005S3.0	557	8.90	10.1	19 11 57	4640	2849
M006S3.0	466	9.44	10.9	27 5 58	5667	4090
F007S3.0	486	9.80	10.1	11 11 58	4018	2421
F008S3.0	465	12.5	12.9	19 5 59	4832	3749
F009S3.0	468	10.0	10.1	11 8 59	4599	3547
M010S3.0	519	12.5	10.3	29 9 59	2898	2799
F011S3.0	541	9.00	10.8	3 11 59	4831	1273
M012S3.0	605	8.43	10.2	6 1 60	4831	2176
F001S4.0	468	8.74	33.3	18 1 55	3682	8817
M002S4.0	567	11.2	32.6	14 2 56	2093	7584
M003S4.0	593	9.83	32.1	11 9 57	2781	5519
F004S4.0	528	8.24	32.1	15 10 57	4844	10373
M005S4.0	562	9.65	30.6	19 11 57	4427	8369
M006S4.0	504	16.0	32.7	3 9 58	3530	9199
F007S4.0	478	10.9	30.9	11 11 58	4664	10560
F008S4.0	465	10.9	40.6	19 5 59	2206	10355
F009S4.0	468	9.56	30.6	11 8 59	4942	10132
M010S4.0	517	8.20	31.3	29 9 59	4242	8493
F011S4.0	542	8.86	32.7	3 11 59	2114	4432
M012S4.0	605	10.9	32.3	6 1 60	4226	7053

E. STRONTIUM - 90

DOG NUMBER	COMMENTS ON DEAD DOGS
F001S2.0	BACTERIAL PNEUMONIA
M002S2.0	UNDETERMINED SOFT TISSUE SARCOMA;LUNG CARCINOMA
M003S2.0	STATUS EPILEPTICUS; THYROID CARCINOMA
F004S2.0	MAMMARY CARCINOMA
M005S2.0	ULCERATIVE STOMATITIS
M006S2.0	UNDIFFERENTIATED SARCOMA (LIVER); NEPHRITIS
F007S2.0	PANCREATIC ISLET CELL ADENOMA
F008S2.0	PNEUMONIA
F009S2.0	UNDETERMINED (NO BONE TUMOR)
M010S2.0	BACTERIAL VALVULAR ENDOCARDITIS
F011S2.0	MAMMARY SARCOMA
M012S2.0	HEPATIC CELL CARCINOMA
F001S3.0	UNDETERMINED (NO BONE TUMOR)
M002S3.0	NEPHRITIS
M003S3.0	SEMINOMA; HYDROCEPHALUS
F004S3.0	MAMMARY CARCINOMA
M005S3.0	SERTOLI CELL TUMOR
M006S3.0	NEPHRITIS; TESTICULAR MALIGNANCY
F007S3.0	MAMMARY CARCINOMA; THYROID CARCINOMA
F008S3.0	UNDETERMINED (NO BONE TUMOR)
F009S3.0	CHROMAPHOBE ADENOMA
M010S3.0	FIBROSARCOMA (GINGIVA)
F011S3.0	PYELONEPHRITIS
M012S3.0	TRANSITIONAL CELL CARCINOMA
F001S4.0	NOT DETERMINED (NO OSTEOSARCOMA)
M002S4.0	SQUAMOUS CELL CARCINOMA -GINGIVA-
M003S4.0	OBTURATING PULMONARY EMBOLISM
F004S4.0	OSTEOSARCOMA; SQUAMOUS CELL CARC. (ORAL), THYROID CARC.
M005S4.0	HEMANGIOSARCOMA (SPLEEN)
M006S4.0	SEMINOMA
F007S4.0	OSTEOSARCOMA
F008S4.0	UNDETERMINED (NO BONE TUMOR)
F009S4.0	UNDETERMINED (NO BONE TUMOR)
M010S4.0	MENINGIOMA; PERIANAL GLAND CARCINOMA
F011S4.0	BLOOD DYSCRASIA,PYOMETRA
M012S4.0	ADENOCARCINOMA NASAL CAVITY

E. STRONTIUM - 90

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
F001S4.5	530	9.00	64.2	16	3	66		3030	9890
M002S4.5	530	12.20	63.6	16	3	66		2707	9660
M003S4.5	530	11.90	63.8	16	3	66		1493	7932
F004S4.5	530	9.80	64.5	16	3	66		2197	12133
M005S4.5	496	13.30	61.3	16	3	66		993	7232
M006S4.5	496	12.00	63.8	16	3	66		2843	9990
F007S4.5	511	9.90	64.5	16	3	66		2813	13480
F008S4.5	511	9.90	64.5	16	3	66		2325	12725
F009S4.5	511	10.30	64.0	16	3	66		1028	6935
M010S4.5	496	14.00	60.9	16	3	66		2064	14240
F011S4.5	496	11.90	63.8	16	3	66		1758	8579
M012S4.5	485	11.40	63.7	16	3	66		2253	13116
F001S5.0	434	9.38	103.	18	1	55		960	11179
M002S5.0	551	12.2	102.	14	2	56		255	4284
M002S5.0A	545	11.4	96.6	7	1	59		1740	16393
M003S5.0	507	10.3	102.	15	10	57		2256	22079
F004S5.0	528	11.4	105.	15	10	57		1448	12703
M005S5.0	621	8.53	95.2	19	11	57		1285	13657
M006S5.0	504	9.33	98.8	3	9	58		35	869
M006S5.0A	462	11.2	94.2	7	1	59		1021	15384
F007S5.0	478	10.2	92.7	11	11	58		1129	14532
F008S5.0	535	11.2	90.5	7	1	59		1469	14843
F009S5.0	459	8.82	93.5	11	8	59		1982	18143
M010S5.0	517	8.55	95.9	29	9	59		990	10209
F011S5.0	542	8.97	102.	3	11	59		1667	13355
M012S5.0	606	12.5	99.2	6	1	60		1165	10837

E. STRONTIUM - 90

DOG NUMBER	COMMENTS ON DEAD DOGS
F001S4.5	PURPURA HEMORRHAGICA
M002S4.5	OSTEOSARCOMA
M003S4.5	SEVERE ANEMIA, INFARCTION, MYELOID METAPLASIA
F004S4.5	HEMANGIOSARCOMA (SPLEEN)
M005S4.5	OSTEOSARCOMA
M006S4.5	OSTEOSARCOMA
F007S4.5	OSTEOSARCOMA; SQUAMOUS CELL CARCINOMA (FRONTAL SINUS)
F008S4.5	HEMANGIOSARCOMA (BONE)
F009S4.5	OSTEOSARCOMA
M010S4.5	SQUAMOUS CELL CARCINOMA (FRONTAL SINUS)
F011S4.5	OSTEOSARCOMA
M012S4.5	OSTEOSARCOMA; HEMANGIOSARCOMA (BONE)
F001S5.0	OSTEOSARCOMA
M002S5.0	STRANGULATED INGUINAL HERNIA
M002S5.0A	OSTEOSARCOMA
M003S5.0	OSTEOSARCOMA
F004S5.0	OSTEOSARCOMA
M005S5.0	SEVERE ANEMIA, AUTOAGGLUTINATION, INFARCTION, SPLENOMEGALY
M006S5.0	INTESTINAL HEMORRHAGE
M006S5.0A	OSTEOSARCOMA, INFARCTION + THROMBOCYTOPENIA
F007S5.0	STATUS EPILEPTICUS
F008S5.0	OSTEOSARCOMA
F009S5.0	SQUAMOUS CELL CARCINOMA ARISING FROM FRONTAL SINUS
M010S5.0	SEVERE ANEMIA + THROMBOCYTOPENIA
F011S5.0	HEMANGIOSARCOMA (LEFT MANDIBLE)
M012S5.0	HEMANGIOSARCOMA (RIB)

F. RADIUM - 224 (QUICKRADIUM)

DOG NUMBER	INJECTION AGE (DAYS)	INJECTION WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79 DEATH	DOSE TO SKELETON (RADS)
MOO1QO.OH	458	11.6		19 5 77	681	
FOO2QO.OH	647	10.7		19 5 77	681	
MOO3QO.OH	646	10.4		30 11 77	486	
FOO4QO.OH	586	10.3		19 5 77	681	
MOO5QO.OH	646	11.3		30 11 77	486	
FOO6QO.OH	586	9.58		19 5 77	681	
MO41QO.O	589	10.1		9 1 79	81	
MO43QO.O	638	9.95		12 9 78	200	
MO45QO.O	673	10.6		12 9 78	200	
FO46QO.O	619	11.2		10 8 77	598	
MO81QO.OH	639	10.4		14 2 79	45	
FO82QO.OH	623	7.80		14 2 79	45	
MO83QO.OH	639	9.17		14 2 79	45	
MOO1Q2.OH	647	11.9	0.291	19 5 77	681	
FOO2Q2.OH	647	10.9	0.317	19 5 77	681	
MOO3Q2.OH	635	9.62	0.359	19 5 77	681	
FOO4Q2.OH	635	8.18	0.423	19 5 77	681	
MOO5Q2.OH	643	10.1	0.342	19 5 77	681	
FOO6Q2.OH	632	9.82	0.352	19 5 77	681	
MOO7Q2.OH	683	10.9	0.317	19 5 77	681	
FOO8Q2.OH	647	11.1	0.312	19 5 77	681	
MOO9Q2.OH	610	11.4	0.303	19 5 77	681	
FO10Q2.OH	610	8.52	0.406	19 5 77	681	
MO11Q2.OH	610	10.3	0.336	19 5 77	681	
FO12Q2.OH	610	8.62	0.401	19 5 77	681	
MO41Q2.O	704	11.2	0.365	9 1 79	81	
FO42Q2.O	662	9.78	0.352	5 12 78	116	
MO43Q2.O	687	9.22	0.355	9 1 79	81	
FO44Q2.O	687	7.99	0.359	9 1 79	81	
MO45Q2.O	621	9.15	0.344	5 12 78	116	
FO46Q2.O	687	10.8	0.362	9 1 79	81	
MO47Q2.O	636	11.1	0.343	30 11 77	486	
FO48Q2.O	603	8.05	0.356	9 1 79	81	
MO49Q2.O	646	12.2	0.348	30 11 77	486	
FO50Q2.O	667	11.4	0.383	12 9 78	200	
MO51Q2.O	636	10.7	0.348	30 11 77	486	
FO52Q2.O	619	11.2	0.344	10 8 77	598	
MO81Q2.OH	662	10.6	0.283	14 2 79	45	
FO82Q2.OH	639	8.68	0.345	14 2 79	45	
MO83Q2.OH	594	8.10	0.370	14 2 79	45	
FO84Q2.OH	594	7.32	0.409	14 2 79	45	

F. RADIUM - 224 (QUICKRADIUM)

DOG NUMBER	COMMENTS ON DEAD DOGS
MOO1QO.OH	
FOO2QO.OH	
MOO3QO.OH	
FOO4QO.OH	
MOO5QO.OH	
FOO6QO.OH	
MO41QO.O	
MO43QO.O	
MO45QO.O	
FO46QO.O	
MO81QO.OH	
FO82QO.OH	
MO83QO.OH	
MOO1Q2.OH	
FOO2Q2.OH	
MOO3Q2.OH	
FOO4Q2.OH	
MOO5Q2.OH	
FOO6Q2.OH	
MOO7Q2.OH	
MOO8Q2.OH	
MOO9Q2.OH	
FO1OQ2.OH	
MO11Q2.OH	
FO12Q2.OH	
MO41Q2.O	
FO42Q2.O	
MO43Q2.O	
FO44Q2.O	
MO45Q2.O	
FO46Q2.O	
MO47Q2.O	
FO48Q2.O	
MO49Q2.O	
FO5OQ2.O	
MO51Q2.O	
FO52Q2.O	
MO81Q2.OH	
FO82Q2.OH	
MO83Q2.OH	
FO84Q2.OH	

F. RADIUM - 224 (QUICKRADIUM)

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
MO85Q2.OH	590	9.23	0.325	14	2	79	45		
FO86Q2.OH	583	8.28	0.362	14	2	79	45		
MOO1Q3.OH	647	10.3	1.06	19	5	77	681		
FOO2Q3.OH	647	10.4	1.05	19	5	77	681		
MOO3Q3.OH	642	10.3	1.06	19	5	77	681		
FOO4Q3.OH	643	8.16	1.33	19	5	77	681		
MOO5Q3.OH	632	11.8	0.922	19	5	77	681		
FOO6Q3.OH	647	10.4	1.05	19	5	77	681		
MOO7Q3.OH	642	11.8	0.922	19	5	77	681		
FOO8Q3.OH	632	9.10	1.20	19	5	77	681		
MOO9Q3.OH	666	13.4	0.822	19	5	77	681		
FO10Q3.OH	666	11.3	0.962	19	5	77	681		
MO11Q3.OH	610	10.5	1.04	19	5	77	681		
FO12Q3.OH	610	9.75	1.12	19	5	77	681		
MO41Q3.O	670	9.98	1.10	5	12	78	116		
FO42Q3.O	705	9.04	1.11	9	1	79	81		
MO43Q3.O	656	9.42	1.12	5	12	78	116		
FO44Q3.O	688	8.42	1.11	9	1	79	81		
MO45Q3.O	704	11.3	1.15	9	1	79	81		
FO46Q3.O	687	9.68	1.15	9	1	79	81		
MO47Q3.O	656	10.2	1.14	9	1	79	81		
FO48Q3.O	687	8.95	1.12	9	1	79	81		
MO49Q3.O	630	9.58	1.12	30	11	77	486		
FO50Q3.O	572	9.40	1.21	12	9	78	200		
MO51Q3.O	638	9.85	1.08	30	11	77	486		
FO52Q3.O	619	9.97	1.10	10	8	77	598		
MO81Q3.OH	657	12.1	0.720	14	2	79	45		
FO82Q3.OH	639	8.73	0.999	14	2	79	45		
MO83Q3.OH	664	8.28	1.05	14	2	79	45		
FO84Q3.OH	594	6.77	1.29	14	2	79	45		
MO85Q3.OH	590	7.75	1.12	14	2	79	45		
FO86Q3.OH	583	8.07	1.08	14	2	79	45		
MOO1Q4.OH	653	10.2	3.23	19	5	77	681		
FOO2Q4.OH	653	9.44	3.49	19	5	77	681		
MOO3Q4.OH	642	13.5	2.44	19	5	77	681		
FOO4Q4.OH	643	9.10	3.62	19	5	77	681		
MOO5Q4.OH	643	10.5	3.14	19	5	77	681		
FOO6Q4.OH	647	10.8	3.05	19	5	77	681		
MO41Q4.O	607	10.9	3.04	30	11	77	486		

F. RADIUM - 224 (QUICKRADIUM)

DOG NUMBER	COMMENTS ON DEAD DOGS
MO85Q2.OH	
FO86Q2.OH	
MO01Q3.OH	
FO02Q3.OH	
MO03Q3.OH	
FO04Q3.OH	
MO05Q3.OH	
FO06Q3.OH	
MO07Q3.OH	
FO08Q3.OH	
MO09Q3.OH	
FO10Q3.OH	
MO11Q3.OH	
FO12Q3.OH	
MO41Q3.O	
FO42Q3.O	
MO43Q3.O	
FO44Q3.O	
MO45Q3.O	
FO46Q3.O	
MO47Q3.O	
FO48Q3.O	
MO49Q3.O	
FO50Q3.O	
MO51Q3.O	
FO52Q3.O	
MO81Q3.OH	
FO82Q3.OH	
MO83Q3.OH	
FO84Q3.OH	
MO85Q3.OH	
FO86Q3.OH	
MO01Q4.OH	
FO02Q4.OH	
MO03Q4.OH	
FO04Q4.OH	
MO05Q4.OH	
FO06Q4.OH	
MO41Q4.O	

F. RADIUM - 224 (QUICKRADIUM)*

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
FO42Q4.O	705	10.8	3.28	9 1 79	81		
MO43Q4.O	662	11.2	3.25	5 12 78	116		
FO44Q4.O	691	7.74	3.28	9 1 79	81		
MO45Q4.O	630	10.2	3.28	30 11 77	486		
FO46Q4.O	674	8.85	3.56	12 9 78	200		
MO81Q4.OH	657	11.O	2.90	14 2 79	45		
FO82Q4.OH	639	8.80	3.62	14 2 79	45		
MO83Q4.OH	608	10.6	3.01	14 2 79	45		
MOO1Q5.OH	653	10.6	8.64	19 5 77	681		
FOO2Q5.OH	653	11.4	8.04	19 5 77	681		
MOO3Q5.OH	643	10.6	8.64	19 5 77	681		
FOO4Q5.OH	647	8.35	10.97	19 5 77	681		
MOO5Q5.OH	635	9.88	9.27	19 5 77	681		
FOO6Q5.OH	647	9.12	10.00	19 5 77	681		
MO41Q5.O	705	11.4	9.65	9 1 79	81		
FO42Q5.O	670	7.76	10.2	5 12 78	116		
MO43Q5.O	697	9.41	9.59	9 1 78		9	324
FO44Q5.O	656	8.08	10.3	5 12 78		16	402
MO45Q5.O	604	9.75	12.O	7 12 77	479		
FO46Q5.O	656	8.22	9.64	9 1 79	81		
MO81Q5.OH	618	8.37	10.O	14 2 79	45		
FO82Q5.OH	664	9.73	8.63	14 2 79	45		
MO83Q5.OH	618	9.00	9.33	14 2 79	45		

*Groups 41-52 received ^{224}Ra in 1 injection; Groups 81-92 received ^{224}Ra in 10 fractions (1/week); Groups 1-12 received ^{224}Ra in 50 fractions (1/week).

F. RADIUM - 224 (QUICKRADIUM)

DOG NUMBER	COMMENTS ON DEAD DOGS
FO42Q4.O	
MO43Q4.O	
FO44Q4.O	
MO45Q4.O	
FO46Q4.O	
MO81Q4.OH	
FO82Q4.OH	
MO83Q4.OH	
MOO1Q5.OH	
FOO2Q5.OH	
MOO3Q5.OH	
FOO4Q5.OH	
MOO5Q5.OH	
FOO6Q5.OH	
MO41Q5.O	
FO42Q5.O	
MO43Q5.O	BLOOD DYSCRASIA
FO44Q5.O	PURPURA HEMORRHAGICA
MO45Q5.O	
FO46Q5.O	
MO81Q5.OH	
FO82Q5.OH	
MO83Q5.OH	

G. AMERICIUM - 241 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
FO13WO.2	533	10.6	0.00179	13 10 66		3815	7
MO14WO.2	533	14.9	0.00178	13 10 66		3185	7
FO24WO.2	477	11.3	0.00181	21 3 68	4027		
FO31WO.2	472	10.9	0.00180	8 5 68		1478	4
MO41WO.2	467	11.9	0.00180	2 7 68	3924		
MO48WO.2	484	11.0	0.00174	30 7 68	3896		
MO49WO.2	498	10.7	0.00175	25 11 69	3413		
FO58WO.2	496	10.4	0.00168	26 1 70		3157	7
MO62WO.2	486	13.3	0.00175	24 2 70	3322		
FO69WO.2	542	10.8	0.00180	22 4 70	3265		
MO78WO.2	501	13.5	0.00178	16 7 70	3180		
MO79WO.2	501	10.0	0.00179	16 7 70	3180		
FO88WO.2	531	8.36	0.00177	25 8 70	3140		
MO95WO.2	526	13.1	0.00173	25 8 70	3140		
FO11WO.5	533	8.17	0.00532	13 10 66	4552		
MO12WO.5	533	11.9	0.00539	13 10 66		3649	25
MO23WO.5	487	12.2	0.00530	21 3 68	4027		
MO29WO.5	472	10.4	0.00548	8 5 68		2239	18
FO30WO.5	472	10.6	0.00538	8 5 68	3979		
FO40WO.5	467	9.40	0.00528	2 7 68	3924		
MO50WO.5	552	11.8	0.00526	25 11 69	3413		
MO59WO.5	496	11.5	0.00503	26 1 70	3351		
MO63WO.5	486	11.4	0.00524	24 2 70	3322		
MO70WO.5	497	12.8	0.00531	22 4 70	3265		
FO80WO.5	501	11.9	0.00545	16 7 70	3180		
FO81WO.5	501	12.1	0.00548	16 7 70	3180		
FO89WO.5	531	9.66	0.00527	25 8 70	3140		
MO96WO.5	490	12.0	0.00533	25 8 70	3140		
FO09W1.0	517	8.60	0.016	15 9 66	4580		
FO10W1.0	517	9.90	0.0162	15 9 66		2750	59
MO20W1.0	513	10.8	0.0161	21 3 68		3060	69
FO21W1.0	513	9.36	0.0166	21 3 68		232	6
FO21W1.0A	552	11.4	0.0159	25 11 69		3262	93
MO22W1.0	487	11.6	0.0164	21 3 68	4027		
MO28W1.0	472	12.1	0.0158	8 5 68		3632	76
FO51W1.0	552	8.25	0.0163	25 11 69	3413		
MO60W1.0	496	10.0	0.0157	26 1 70	3351		
MO64W1.0	486	10.4	0.0158	24 2 70		3134	76
FO71W1.0	485	12.1	0.0157	22 4 70	3265		

G. AMERICIUM - 241 *

DOG NUMBER	COMMENTS ON DEAD DOGS
FO13WO.2	UNDETERMINED (NO BONE TUMOR)
MO14WO.2	HEMANGIOSARCOMA (SPLEEN)
FO24WO.2	
FO31WO.2	LUNG CARCINOMA
MO41WO.2	
MO48WO.2	
MO49WO.2	
FO58WO.2	TRAUMA
MO62WO.2	
FO69WO.2	
MO78WO.2	
MO79WO.2	
FO88WO.2	
MO95WO.2	
FO11WO.5	
MO12WO.5	PANCREATIC DYSTROPHY
MO23WO.5	
MO29WO.5	MALIGNANT MELANOMA (ORAL)
FO3OWO.5	
FO4OWO.5	
MO5OWO.5	
MO59WO.5	
MO63WO.5	
MO7OWO.5	
FO8OWO.5	
FO81WO.5	
FO89WO.5	
MO96WO.5	
FOO9W1.O	
FO1OW1.O	LUNG CARCINOMA
MO2OW1.O	MYXOSARCOMA (LIVER)
FO21W1.O	ACCIDENTAL STRANGULATION
FO21W1.OA	MAST CELL LEUKEMIA
MO22W1.O	
MO28W1.O	EPIDERMOID CARCINOMA (GINGIVA)
FO51W1.O	
MO6OW1.O	
MO64W1.O	THROMBO-EMBOLISM
FO71W1.O	

G. AMERICIUM - 241 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
MO82W1.0	501	12.4	0.0163	16	7	70	3180		
FO9OW1.0	526	10.9	0.0160	25	8	70	3140		
MO97W1.0	490	10.4	0.0160	25	8	70		2530	63
F122W1.0	504	9.38	0.0150	6	11	75	1241		
M123W1.0	516	11.8	0.0156	9	12	75	1208		
F124W1.0	516	8.36	0.0157	9	12	75	1208		
F127W1.0	494	8.89	0.0152	6	11	75	1241		
M128W1.0	493	13.2	0.0153	6	11	75	1241		
F13OW1.0	491	10.3	0.0153	6	11	75	1241		
M132W1.0	482	9.86	0.0153	6	11	75	1241		
M134W1.0	490	9.03	0.0150	6	11	75	1241		
F137W1.0	515	7.71	0.0154	9	12	75	1208		
F138W1.0	514	8.63	0.0152	9	12	75	1208		
M139W1.0	513	9.11	0.0157	9	12	75	1208		
F141W1.0	504	8.89	0.0154	9	12	75	1208		
FO42W1.7	495	9.26	0.0484	30	7	68		2960	215
FO43W1.7	492	10.4	0.0481	30	7	68		3666	247
FO44W1.7	492	7.46	0.0473	30	7	68		3306	249
MO45W1.7	492	11.9	0.0486	30	7	68	3896		
MO46W1.7	484	8.42	0.0479	30	7	68		2848	170
MO47W1.7	484	11.1	0.0486	30	7	68		3486	233
FO52W1.7	552	9.57	0.0493	25	11	69	3413		
MO61W1.7	496	10.7	0.0458	26	1	70	3351		
MO65W1.7	486	11.2	0.0471	24	2	70	3322		
FO72W1.7	500	11.1	0.0479	22	4	70	3265		
MO83W1.7	501	12.6	0.0493	16	7	70	3180		
FO91W1.7	490	13.3	0.0480	25	8	70		2193	127
MO98W1.7	490	13.3	0.0480	25	8	70	3140		
F115W1.7	502	8.73	0.0468	17	10	74	1626		
F116W1.7	502	8.56	0.0470	17	10	74	1626		
F121W1.7	504	9.36	0.0458	6	11	75	1241		
M125W1.7	515	10.0	0.0471	9	12	75	1208		
F126W1.7	494	9.63	0.0456	6	11	75	1241		
M129W1.7	493	8.26	0.0453	6	11	75	1241		
F131W1.7	491	9.16	0.0457	6	11	75	1241		
M133W1.7	491	10.8	0.0459	6	11	75	1241		
M135W1.7	490	10.0	0.0458	6	11	75	1241		
F136W1.7	522	8.91	0.0461	9	12	75	1208		
M14OW1.7	513	10.5	0.0469	9	12	75	1208		

G. AMERICIUM - 241 *

DOG NUMBER	COMMENTS ON DEAD DOGS
MO82W1.O	
FO9OW1.O	
MO97W1.O	THROMBOSIS RIGHT HEART CHAMBERS
F122W1.O	
M123W1.O	
F124W1.O	
F127W1.O	
M128W1.O	
F13OW1.O	
M132W1.O	
M134W1.O	
F137W1.O	
F138W1.O	
M139W1.O	
F141W1.O	
FO42W1.7	LYMPHOSARCOMA
FO43W1.7	POST SURGICAL HEMORRHAGE
FO44W1.7	UNDIFFERENTIATED MALIGNANCY (SOFT TISSUE)
MO45W1.7	
MO46W1.7	STATUS EPILEPTICUS
MO47W1.7	HEPATIC HEMORRHAGE
FO52W1.7	
MO61W1.7	
MO65W1.7	
FO72W1.7	
MO83W1.7	
FO91W1.7	BLOOD DYSCRASIA
MO98W1.7	
F115W1.7	
F116W1.7	
F121W1.7	
M125W1.7	
F126W1.7	
M129W1.7	
F131W1.7	
M133W1.7	
M135W1.7	
F136W1.7	
M14OW1.7	

G. AMERICIUM - 241 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
FOO7W2.O	561	12.60	0.0952	15	9	66		1847	226
FOO8W2.O	561	11.7O	0.0957	15	9	66		2841	362
MO19W2.O	513	13.4	0.097O	21	3	68		2785	368
MO27W2.O	473	12.7	0.0961	8	5	68		2887	347
MO38W2.O	477	9.88	0.0945	2	7	68		3047	427
FO39W2.O	468	9.21	0.0948	2	7	68		3066	473
MO53W2.O	498	9.24	0.0960	25	11	69		3055	434
FO66W2.O	486	9.12	0.0935	24	2	70	3322		
MO73W2.O	552	14.3	0.0965	17	6	70		2476	324
FO84W2.O	493	10.6	0.0984	16	7	70		2773	398
MO85W2.O	493	10.8	0.0987	16	7	70	3180		
FO92W2.O	490	10.6	0.0962	25	8	70		2318	345
MOO5W3.O	561	15.OO	0.305	15	9	66		1917	792
FOO6W3.O	561	11.9	0.310	15	9	66		1510	664
FO18W3.O	523	8.60	0.307	21	3	68		1756	823
MO26W3.O	473	12.4	0.310	8	5	68		2127	1022
MO36W3.O	477	11.O	0.305	2	7	68		1696	749
FO37W3.O	468	8.44	0.294	2	7	68		1764	716
MO54W3.O	498	10.5	0.306	25	11	69		1876	969
MO67W3.O	485	11.8	0.295	24	2	70		1883	904
FO74W3.O	542	10.O	0.302	22	4	70		1700	727
FO75W3.O	555	9.42	0.308	17	6	70		1533	765
MO86W3.O	493	11.3	0.312	16	7	70		1558	761
FO93W3.O	490	11.2	0.301	25	8	70		1884	903
M1OOW3.O	542	11.O	0.304	2	12	70		1198	575
MOO3W4.O	517	12.60	0.897	28	6	66		1779	2787
FOO4W4.O	517	9.40	0.911	28	6	66		1533	2393
MO17W4.O	523	9.87	0.924	21	3	68		1132	1711
FO25W4.O	473	10.5	0.927	8	5	68		1527	2465
MO34W4.O	477	10.7	0.893	2	7	68		1566	2011
FO35W4.O	477	8.87	0.902	2	7	68		1323	2065
FO55W4.O	498	8.37	0.914	25	11	69		1388	2390
MO68W4.O	485	11.8	0.890	24	2	70		1415	1980
FO76W4.O	485	9.37	0.899	22	4	70		1569	2359
MO77W4.O	500	10.5	0.906	22	4	70		633	945
MO87W4.O	501	13.1	0.916	16	7	70		1300	1881
FO94W4.O	490	11.3	0.912	25	8	70		1381	2159

G. AMERICIUM - 241 *

DOG NUMBER	COMMENTS ON DEAD DOGS
FOO7W2.O	OSTEOSARCOMA
FOO8W2.O	OSTEOSARCOMA
MO19W2.O	FIBROSARCOMA (LIVER)
MO27W2.O	MAST CELL SARCOMA
MO38W2.O	OSTEOSARCOMA
FO39W2.O	OSTEOSARCOMA; ADENOCARCINOMA (NASAL CAVITY)
MO53W2.O	OSTEOSARCOMA
FO66W2.O	
MO73W2.O	COLLAPSED VERTEBRA
FO84W2.O	OSTEOSARCOMA
MO85W2.O	
FO92W2.O	OSTEOSARCOMA
MOO5W3.O	OSTEOSARCOMA
FOO6W3.O	OSTEOSARCOMA
FO18W3.O	OSTEOSARCOMA
MO26W3.O	OSTEOSARCOMA; FIBROSARCOMA (BONE); HEPATOMA
MO36W3.O	OSTEOSARCOMA
FO37W3.O	OSTEOSARCOMA
MO54W3.O	OSTEOSARCOMA
MO67W3.O	KIDNEY DEGENERATION; THYROID DEGENERATION
FO74W3.O	OSTEOSARCOMA
FO75W3.O	OSTEOSARCOMA
MO86W3.O	OSTEOSARCOMA
FO93W3.O	OSTEOSARCOMA
M1OOW3.O	OSTEOSARCOMA
MOO3W4.O	OSTEOSARCOMA; NEPHRITIS
FOO4W4.O	KIDNEY, THYROID AND LIVER DEGENERATION
MO17W4.O	OSTEOSARCOMA; THROMBOSIS
FO25W4.O	MESOTHELIOMA; KIDNEY DEGENERATION
MO34W4.O	OSTEOSARCOMA
FO35W4.O	PANCREATIC ADENOCARCINOMA
FO55W4.O	OSTEOSARCOMA
MO68W4.O	OSTEOSARCOMA
FO76W4.O	OSTEOSARCOMA
MO77W4.O	LIVER DEGENERATION
MO87W4.O	OSTEOSARCOMA
FO94W4.O	OSTEOSARCOMA

G. AMERICIUM - 241 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79 DEATH	DOSE TO SKELETON (RADS)
MOO1W5.O	517	10.4	2.78	28 6 66	401	1970
MOO2W5.O	517	12.7	2.83	28 6 66	448	2169

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* Measurements made to date indicate the liver dose to be approximately 4 times that to the skeleton

The original "T" (test) designation for the above animals has been changed to "M" or "F" (male or female toxicity) designations. For example, the male dog originally injected as TOOW5.O is now redesignated as MOO1W5.O.

G. AMERICIUM - 241 *

DOG NUMBER	COMMENTS ON DEAD DOGS
MO01W5.0	LIVER DEGENERATION; KIDNEY DEGENERATION
MO02W5.0	LIVER DEGENERATION; KIDNEY DEGENERATION

H. CALIFORNIUM - 252

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
MOO1FO.O	562	12.0		1 2 72	2615		
FOO2FO.O	545	10.6		3 1 73	2278		
FOO3FO.O	545	9.43		3 1 73	2278		
FOO4FO.O	492	10.6		27 2 73	2223		
MOO5FO.O	562	10.4		1 2 72	2615		
MOO6FO.O	509	10.9		28 11 72	2314		
MOO1FO.1	498	13.0	0.00060	26 7 72	2439		
FOO2FO.1	524	9.15	0.00064	2 11 72	2340		
FOO3FO.1	545	10.1	0.00075	3 1 73	2278		
FOO4FO.1	492	9.44	0.00060	27 2 73	2223		
MOO5FO.1	498	10.4	0.00060	26 7 72	2439		
MOO6FO.1	524	10.3	0.00062	2 11 72	2340		
MOO1FO.5	498	12.2	0.00525	26 7 72	2439		
FOO2FO.5	513	11.0	0.00529	2 11 72	2340		
FOO3FO.5	511	8.89	0.00525	27 2 73	2223		
FOO4FO.5	485	11.2	0.00518	27 2 73	2223		
MOO5FO.5	494	9.44	0.00530	26 7 72	2439		
MOO6FO.5	524	11.0	0.00529	2 11 72	2340		
MOO1F1.O	586	9.69	0.0163	8 9 71	2761		
FOO2F1.O	586	8.28	0.0167	8 9 71	2761		
FOO3F1.O	539	8.89	0.0167	8 9 71	2761		
FOO4F1.O	539	10.0	0.0165	8 9 71	2761		
MOO5F1.O	539	12.9	0.0165	8 9 71	2761		
MOO6F1.O	513	9.67	0.0165	2 11 72	2340		
MOO1F2.O	498	11.5	0.0922	26 7 72	2439		
FOO2F2.O	545	9.85	0.0905	3 1 73	2278		
FOO3F2.O	511	9.16	0.0907	27 2 73	2223		
FOO4F2.O	473	9.33	0.0910	27 2 73	2223		
MOO5F2.O	494	10.2	0.0905	26 7 72	2439		
MOO6F2.O	513	11.4	0.0912	2 11 72	2340		
MOO1F3.O	583	11.6	0.289	3 3 71		1546	1069
FOO2F3.O	583	10.6	0.289	3 3 71		1730	1075
FOO3F3.O	583	8.66	0.292	3 3 71		2030	1104

H. CALIFORNIUM - 252

DOG NUMBER	COMMENTS ON DEAD DOGS
M001F0.0	
F002F0.0	
F003F0.0	
F004F0.0	
M005F0.0	
M006F0.0	
M001F0.1	
F002F0.1	
F003F0.1	
F004F0.1	
M005F0.1	
M006F0.1	
M001F0.5	
F002F0.5	
F003F0.5	
F004F0.5	
M005F0.5	
M006F0.5	
M001F1.0	
F002F1.0	
F003F1.0	
F004F1.0	
M005F1.0	
M006F1.0	
M001F2.0	
F002F2.0	
F003F2.0	
F004F2.0	
M005F2.0	
M006F2.0	
M001F3.0	FIBROSARCOMA (SKELETON)
F002F3.0	OSTEOSARCOMA
F003F3.0	OSTEOSARCOMA

H. CALIFORNIUM - 252

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
FOO4F3.O	583	9.69	O.295	3 3 71		2O15	1167
MOO5F3.O	524	11.1	O.284	28 11 72		1675	1108
MOO6F3.O	513	1O.2	O.293	2 11 72		1846	112O

H. CALIFORNIUM - 252

DOG NUMBER	COMMENTS ON DEAD DOGS
FOO4F3.O	OSTEOSARCOMA
MOO5F3.O	OSTEOSARCOMA
MOO6F3.O	OSTEOSARCOMA

I. CALIFORNIUM - 249

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
FO01G0.0	499	7.77		23 10 73	1985		
MO02G0.0	509	10.5		28 11 72	2314		
MO03G0.0	509	10.1		28 11 72	2314		
FO04G0.0	502	11.1		5 3 74		269	
FO05G0.0	514	11.0		30 5 74	1766		
MO06G0.0	499	11.4		23 10 73	1985		
FO01G0.1	499	9.91	0.00061	23 10 73	1985		
MO02G0.1	486	13.1	0.00063	5 7 72	2460		
MO03G0.1	486	10.1	0.00063	5 7 72	2460		
FO04G0.1	488	11.4	0.00060	24 4 74	1802		
FO05G0.1	488	8.70	0.00060	24 4 74	1802		
MO06G0.1	486	11.6	0.00064	5 7 72	2460		
FO01G0.5	499	9.20	0.00485	23 10 73	1985		
MO02G0.5	514	12.0	0.00514	29 2 72	2587		
MO03G0.5	514	12.6	0.00518	29 2 72	2587		
FO04G0.5	471	10.9	0.00516	5 3 74	1852		
FO05G0.5	504	11.3	0.00559	30 5 74	1766		
MO06G0.5	514	11.8	0.00511	29 2 72		2037	22
FO01G1.0	555	8.58	0.0154	16 12 71		1584	48
MO02G1.0	486	11.4	0.0152	5 7 72	2460		
MO03G1.0	486	11.5	0.0154	5 7 72	2460		
FO04G1.0	555	10.5	0.0154	16 12 71	2662		
FO05G1.0	471	9.29	0.0153	5 3 74	1852		
MO06G1.0	524	10.6	0.0160	28 11 72	2314		
FO01G2.0	558	9.32	0.0905	16 12 71		2029	372
MO02G2.0	555	11.0	0.0916	16 12 71		2301	416
MO03G2.0	486	10.8	0.0935	5 7 72	2460		
FO04G2.0	558	10.3	0.0915	16 12 71		2561	437
FO05G2.0	555	9.44	0.0913	16 12 71	2662		
MO06G2.0	524	10.0	0.0963	28 11 72	2314		
FO01G3.0	584	11.6	0.290	24 2 71		1716	960
MO02G3.0	580	13.2	0.282	24 2 71		1770	977
MO03G3.0	580	13.7	0.284	24 2 71		1464	791

I. CALIFORNIUM - 249

DOG NUMBER	COMMENTS ON DEAD DOGS
F001G0.0	
M002G0.0	
M003G0.0	
F004G0.0	ACCIDENTAL STRANGULATON
F005G0.0	
M006G0.0	
F001G0.1	
M002G0.1	
M003G0.1	
F004G0.1	
F005G0.1	
M006G0.1	
F001G0.5	
M002G0.5	
M003G0.5	
F004G0.5	
F005G0.5	
M006G0.5	NASAL ADENOCARCINOMA
F001G1.0	STATUS EPILEPTICUS
M002G1.0	
M003G1.0	
F004G1.0	
F005G1.0	
M006G1.0	
F001G2.0	OSTEOSARCOMA
M002G2.0	EPIDERMOID CARCINOMA (TYMPANIC BULLA)
M003G2.0	
F004G2.0	OSTEOSARCOMA
F005G2.0	
M006G2.0	
F001G3.0	OSTEOSARCOMA
M002G3.0	OSTEOSARCOMA
M003G3.0	OSTEOSARCOMA

I. CALIFORNIUM - 249

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
FOO4G3.O	580	8.79	O.283	24 2 71		1541	932
FOO5G3.O	514	9.12	O.380	30 5 74		1657	1273
MOO6G3.O	524	10.1	O.293	28 11 72		1322	807

I. CALIFORNIUM - 249

DOG NUMBER	COMMENTS ON DEAD DOGS
FOO4G3.O	OSTEOSARCOMA
FOO5G3.O	OSTEOSARCOMA
MOO6G3.O	OSTEOSARCOMA

J. EINSTIENIUM - 253 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
FOO1E3.O	47O	11.2	O.284	5 6 73	2125		
MOO3E3.O	47O	11.3	O.288	5 6 73	2125		
MOO4E3.O	47O	7.93	O.294	5 6 73	2125		
FOO1E5.O	495	8.7O	2.85	5 6 73	2125		
FOO2E5.OG	483	9.21	2.81	5 6 73		2OO9	1O15
MOO3E5.O	47O	1O.4	2.84	5 6 73	2125		

* FOO2E5.OG recieved O.318 uCi/kg of 249Cf on 28 May 1974.

J. EINSTIENIUM - 253 *

DOG NUMBER	COMMENTS ON DEAD DOGS
F001E3.0	
M003E3.0	
M004E3.0	
F001E5.0	
F002E5.0G	OSTEOSARCOMA
M003E5.0	

TABLE II. TEST ANIMALS (31 MAR. 1979)

A. RADIUM - 226 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
TO01R5.O	996	11.1	10.3	1 12 52		1074	12625
TO02R5.O	920	8.40	4.39	12 1 53		1368	6299
TO03R5.O	1467	8.29	4.76	12 1 53		428	1755
TO04R5.O	459	10.0	10.6	6 7 53		1	32
TO05R5.O	126	6.14	11.7	6 10 53		1	33
TO06R5.O	126	6.14	11.4	6 10 53		1	32
TO07R5.O	126	6.14	11.8	6 10 53		1	33
TO08R5.O	290	5.52	1.92	10 5 55		58	651
TO09R5.O	2275	10.4	1.94	10 5 55		58	780
TO10R5.O	43	1.02	1.98	10 5 55		49	391
TO11R5.O	43	1.58	1.91	10 5 55		49	484
TO12R5.O	397	12.3	9.72	9 5 56		220	3609
TO13R5.O	397	7.59	9.76	9 5 56		188	3092
TO14R4.O	674	8.12	3.17	11 7 56		72	507
TO15R4.O	672	9.03	3.11	11 7 56		2127	6823
TO16R5.O	604	12.4	9.68	11 7 57		12	244
TO17R5.OH	383	12.2	9.87	28 10 58		1140	18207
TO18R5.OH	383	11.1	10.8	28 10 58		1226	16837
TO19R5.OH	383	11.3	10.7	28 10 58		1219	15440
TO20R5.OH	383	11.4	10.6	28 10 58		1340	18641
TO21R5.OH	381	11.8	10.1	28 10 58		386	4947
TO22R5.OH	381	11.9	10.1	28 10 58		587	7881
TO23R4.OH	384	9.50	4.05	25 11 58		1471	5787
TO24R4.OH	384	11.9	3.24	25 11 58		1505	7457
TO25R4.OH	379	11.3	3.42	25 11 58		1309	6229
TO26R4.OH	379	11.0	3.48	25 11 58		1780	6292
TO27R4.OH	372	11.5	3.34	25 11 58		1414	4509
TO28R3.OH	372	11.7	1.11	25 11 58		387	476
TO29R5.O	474	13.5	10.4	3 3 59		216	4539
TO30R5.O	474	11.5	10.4	3 3 59		178	3801
TO31R5.O	471	10.5	10.4	3 3 59		303	6344
TO32R3.O	471	11.4	1.13	3 3 59		2249	2485
TO33R3.O	471	10.6	1.15	3 3 59		1822	2561
TO34R3.O	470	15.7	1.12	3 3 59		1737	2137
TO35R3.OJ	670	9.44	0.951	5 5 59		8	19
TO36R4.O	695	10.2	2.99	22 12 60		1154	4863
TO37R4.O	695	9.53	3.00	22 12 60		1627	4312

A. RADIUM - 226 *

DOG NUMBER	COMMENTS ON DEAD DOGS
TO01R5.O	OSTEOSARCOMA
TO02R5.O	OSTEOSARCOMA
TO03R5.O	SPECIAL STUDY
TO04R5.O	SPECIAL STUDY
TO05R5.O	SPECIAL STUDY
TO06R5.O	SPECIAL STUDY
TO07R5.O	SPECIAL STUDY
TO08R5.O	SPECIAL STUDY
TO09R5.O	SPECIAL STUDY
TO10R5.O	SPECIAL STUDY
TO11R5.O	SPECIAL STUDY
TO12R5.O	SPECIAL STUDY
TO13R5.O	SPECIAL STUDY
TO14R4.O	SPECIAL STUDY
TO15R4.O	OSTEOSARCOMA
TO16R5.O	SPECIAL STUDY
TO17R5.OH	OSTEOSARCOMA + ULCERATIVE GINGIVITIS
TO18R5.OH	OSTEOSARCOMA + ULCERATIVE GINGIVITIS
TO19R5.OH	OSTEOSARCOMA + ULCERATIVE GINGIVITIS
TO20R5.OH	OSTEOSARCOMA + ULCERATIVE GINGIVITIS
TO21R5.OH	NEPHRITIS
TO22R5.OH	CRIPPLING FRACTURES
TO23R4.OH	OSTEOSARCOMA
TO24R4.OH	OSTEOSARCOMA
TO25R4.OH	OSTEOSARCOMA
TO26R4.OH	OSTEOSARCOMA
TO27R4.OH	OSTEOSARCOMA
TO28R3.OH	SPECIAL STUDY
TO29R5.O	NEPHRITIS
TO30R5.O	NEPHRITIS
TO31R5.O	NEPHRITIS
TO32R3.O	OSTEOSARCOMA
TO33R3.O	OSTEOSARCOMA, NEPHRITIS
TO34R3.O	OSTEOSARCOMA
TO35R3.OJ	SPECIAL STUDY
TO36R4.O	OSTEOSARCOMA
TO37R4.O	OSTEOSARCOMA

A. RADIUM - 226 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79 DEATH	DOSE TO SKELETON (RADS)
TO38R4.O	695	10.1	3.02	22 12 60	1503	4876
TO4OR1.O	899	13.O	O.O483	3 4 62	7	1
TO41R1.O	899	12.7	O.O487	3 4 62	63	4
TO42R1.7	967	14.O	O.146	4 4 62	7	3
TO43R1.7	963	13.2	O.145	4 4 62	64	15
TO44R3.O	938	11.1	O.937	4 4 62	68	95
TO45R3.O	939	13.6	O.941	5 4 62	7	16
TO46R3.O	81O	12.5	O.928	5 4 62	69	137
TO47R6.O	99	5.27	29.4	11 6 62	4	469
TO48R6.O	2842	11.2	25.1	27 12 62	49	2129
TO49R5.O	485	10.6	7.54	2 5 63	5	148
TO5OR5.O	485	13.7	7.46	2 5 63	15	365
TO51R5.O	418	13.3	8.48	8 5 63	92	2252
TO52R5.O	418	10.7	8.57	8 5 63	15	344
TO53R5.O	418	12.O	8.5O	8 5 63	33	815
TO54R5.O	417	11.4	8.76	22 5 63	5	117
TO55R5.O	417	11.6	8.61	22 5 63	33	712
TO56R5.O	417	11.6	8.61	22 5 63	9O	1948
TO57R4.O	5O1	12.1	2.72	15 8 63	14	72
TO58R4.O	496	11.7	2.41	15 8 63	61	381
TO59R4.O	496	9.64	2.57	15 8 63	6O	363
TO6OR4.O	49O	12.1	2.33	15 8 63	117	553
TO61R4.O	49O	9.48	2.7O	15 8 63	371	2089
TO62R4.O	49O	8.63	2.68	15 8 63	46O	2115
TO63R3.O	559	8.72	O.899	29 1 64	36	68
TO64R3.O	551	8.42	O.919	29 1 64	63	97
TO65R3.O	551	11.6	O.922	29 1 64	7O	132
TO66R3.O	549	10.1	O.9O4	29 1 64	132	187
TO67R3.O	549	12.7	O.898	29 1 64	134	224
TO68R3.O	549	12.1	O.917	29 1 64	1667	1377
TO69R3.O	499	8.84	O.919	29 1 64	622	868
TO7OR3.O	499	14.2	O.922	29 1 64	1996	2819
TO71R5.O	4O25	13.8	9.23	28 1 69	42	931
TO72R5.O	4776	9.45	12.4	17 8 72	54	1593

A. RADIUM - 226 *

DOG NUMBER	COMMENTS ON DEAD DOGS
TO38R4.O	OSTEOSARCOMA
TO4OR1.O	SPECIAL STUDY
TO41R1.O	SPECIAL STUDY
TO42R1.7	SPECIAL STUDY
TO43R1.7	SPECIAL STUDY
TO44R3.O	SPECIAL STUDY
TO45R3.O	SPECIAL STUDY
TO46R3.O	SPECIAL STUDY
TO47R6.O	SPECIAL STUDY
TO48R6.O	LEUKOPENIA, PNEUMONIA + SPECIAL MELANOMA STUDY
TO49R5.O	SPECIAL STUDY
TO5OR5.O	SPECIAL STUDY
TO51R5.O	SPECIAL STUDY
TO52R5.O	SPECIAL STUDY
TO53R5.O	SPECIAL STUDY
TO54R5.O	SPECIAL STUDY
TO55R5.O	SPECIAL STUDY
TO56R5.O	SPECIAL STUDY
TO57R4.O	SPECIAL STUDY
TO58R4.O	SPECIAL STUDY
TO59R4.O	SPECIAL STUDY
TO6OR4.O	SPECIAL STUDY
TO61R4.O	SPECIAL STUDY
TO62R4.O	SPECIAL STUDY
TO63R3.O	SPECIAL STUDY
TO64R3.O	SPECIAL STUDY
TO65R3.O	SPECIAL STUDY
TO66R3.O	SPECIAL STUDY
TO67R3.O	SPECIAL STUDY
TO68R3.O	OSTEOSARCOMA
TO69R3.O	SPECIAL STUDY
TO7OR3.O	OSTEOSARCOMA
TO71R5.O	MELANOMA ORAL CAVITY
TO72R5.O	SPECIAL STUDY

A. RADIUM - 226 *

DOG NUMBER	INJECTION AGE (DAYS)	INJECTION WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DAYS SINCE INJECTION DEATH	DOSE TO SKELETON (RADS)
TO73R2.O	487	8.68	0.35O	6 5 75		380	225
TO74R2.O	488	12.O	O.314	13 5 75		28	21
TO75RO.O	488	9.38		13 5 75		134	
TO76R2.O	488	11.6	O.318	13 5 75		56	41
TO77R2.O	489	12.3	O.313	14 5 75		7	5
TO78RO.O	5O3	9.77		28 5 75		55	
TO79R2.O	5O3	9.23	O.357	28 5 75		127	94
TO8ORO.O	5OO	12.1		28 5 75		2O8	
TO81R2.O	495	11.1	O.365	28 5 75		2O5	143
TO82R2.O	495	1O.3	O.359	28 5 75		28	24
TO83RO.O	495	8.O6		28 5 75		26	
TO84R2.O	512	11.O	O.314	6 6 75		132	85
TO85R2.O	49O	9.24	O.265	1O 6 75		21O	1O6
TO86R2.O	487	13.8	O.313	24 6 75		15	11
TO87RO.O	488	12.2		25 6 75		15	
TO88R2.O	49O	11.7	O.328	1 7 75		365	2O4
TO89R2.O	491	12.2	O.329	2 7 75		15	12
TO9ORO.O	5O2	9.63		9 7 75		7	
TO91R2.O	513	1O.3	O.253	1O 6 75		56	32
TO92R2.O	459	11.6	O.327	5 8 75		7	5
TO93R3.O	576	7.75	O.969	27 1 76		3	7
TO94R3.O	571	9.88	O.93O	23 1 76		11	25
TO95R3.O	58O	1O.2	1.O3	13 2 76		14	35
TO96R3.O	584	7.94	O.99O	13 2 76		14	33
TO97R3.O	583	1O.8	O.972	26 2 76		4	1O
TO98R3.O	549	9.51	O.966	2O 2 76		18	42
TO99R2.OE	563	55.4	O.335	3 11 77	513		
T1OOR2.OE	49O	48.6	O.341	22 11 77	494		

A. RADIUM - 226 *

DOG NUMBER	COMMENTS ON DEAD DOGS
TO73R2.O	SPECIAL STUDY
TO74R2.O	SPECIAL STUDY
TO75RO.O	SPECIAL STUDY
TO76R2.O	SPECIAL STUDY
TO77R2.O	SPECIAL STUDY
TO78RO.O	SPECIAL STUDY
TO79R2.O	SPECIAL STUDY
TO8ORO.O	SPECIAL STUDY
TO81R2.O	SPECIAL STUDY
TO82R2.O	SPECIAL STUDY
TO83RO.O	SPECIAL STUDY
TO84R2.O	SPECIAL STUDY
TO85R2.O	SPECIAL STUDY
TO86R2.O	SPECIAL STUDY
TO87RO.O	SPECIAL STUDY
TO88R2.O	SPECIAL STUDY
TO89R2.O	SPECIAL STUDY
TO9ORO.O	SPECIAL STUDY
TO91R2.O	SPECIAL STUDY
TO92R2.O	SPECIAL STUDY
TO93R3.O	SPECIAL STUDY
TO94R3.O	SPECIAL STUDY
TO95R3.O	SPECIAL STUDY
TO96R3.O	SPECIAL STUDY
TO97R3.O	SPECIAL STUDY
TO98R3.O	SPECIAL STUDY
TO99R2.OE	
T1OOR2.OE	

A. RADIUM - 226 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79 DEATH	DOSE TO SKELETON (RADS)
T101R3.0E	490	45.6	1.05	22 11 77	494	
T102R2.0E	501	47.3	0.342	9 12 77	477	
T103R3.0E	501	45.4	1.10	9 12 77	477	
T104R0.5E	519	47.9	0.0191	27 12 77	459	
T105R1.0E	519	49.5	0.0558	27 12 77	459	
T106R0.1E	535	46.9	0.0021	12 1 78	443	

*

The multiple injection dogs were male beagles born in Davis, California, but injected in our laboratory. Each was injected 6 times over a 280 day period with 56 days between each injection. Each 226 Ra injection was 20.0 uCi for the dogs T17R5H - T22R5H; 6.41 uCi for T23R4H - T27R4H; and 2.16 uCi for T28R3H. Tabulated for each dog are his age at 1st injection, his average weight during the injection period, total uCi/average weight, the date of 1st injection, the time from 1st injection to death, and sum of the skeletal doses computed from each injection to death.

T35R3J also recieved 99 uCi 85 Sr
T39R0.0 has been reassigned and is now M12M0.0.

A. RADIUM - 226 *

DOG NUMBER	COMMENTS ON DEAD DOGS
T101R3.0E	
T102R2.0E	
T103R3.0E	
T104R0.5E	
T105R1.0E	
T106R0.1E	

B. PLUTONIUM - 239 *

DOG NUMBER	INJECTION AGE (DAYS)	INJECTION WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79 DEATH	DOSE TO SKELETON (RADS)
TOOOP5.O	647	11.4	3.05	24 6 52	1	5
TOO1P5.O	1581	12.7	3.04	13 10 52	29	156
TOO2P5.O	914	11.9	6.85	15 9 52	44	534
TOO3P5.O	942	9.65	3.22	13 10 52	610	3361
TOO4P5.O	1016	8.78	3.02	13 10 52	365	1912
TOO5P5.O	474	10.4	2.69	14 12 54	400	1862
TOO6P5.O	527	6.16	2.73	14 12 54	406	1918
TOO7P5.O	475	7.40	2.68	14 12 54	777	3534
TOO8P5.O	527	8.32	2.67	14 12 54	863	3896
TOO9P5.O	551	10.3	2.80	22 11 55	15	75
TO1OP5.O	534	11.9	2.74	23 11 55	15	73
TO11P5.O	516	12.1	2.76	22 11 55	28	137
TO12P5.O	487	9.23	2.74	23 11 55	28	136
TO13P5.O	587	8.27	3.16	24 4 56	3	17
TO14P5.O	587	9.38	2.43	24 4 56	7	30
TO15P5.O	737	8.32	2.79	15 10 56	1	5
TO16P5.O	673	10.7	2.85	10 10 56	92	463
TO17P5.O	739	11.1	3.01	12 2 57	210	1107
TO18P5.O	739	8.16	2.83	12 2 57	217	1075
TO19P5.O	688	8.86	2.91	15 12 60	1400	6752
TO2OP5.O	688	13.O	2.68	15 12 60	474	2189
TO21P5.O	688	10.3	2.72	15 12 60	939	4304
TO23P1.O	1485	13.1	O.0172	28 7 61	96	3
TO24P1.O	559	13.1	O.0172	28 7 61	97	3
TO25P1.O	559	13.8	O.0167	28 7 61	467	12
TO26P1.O	556	12.O	O.0160	28 7 61	647	15
TO27P3.O	556	11.5	O.332	28 7 61	755	402
TO28P1.O	552	10.5	O.0150	9 8 61	559	13
TO29P3.O	552	12.1	O.296	9 8 61	560	272
TO3OP1.O	548	12.4	O.0148	9 8 61	30	<1
TO31P3.O	520	13.O	O.3O5	9 8 61	40	21
TO32P1.O	520	8.47	O.0162	9 8 61	274	7
TO33P1.O	550	10.7	O.0153	15 9 61	375	9
TO34P1.O	550	9.68	O.0154	15 9 61	746	17
TO35P3.O	550	11.9	O.3O3	15 9 61	362	184

B. PLUTONIUM - 239 *

DOG NUMBER	COMMENTS ON DEAD DOGS
TOOOP5.O	SPECIAL STUDY
TOO1P5.O	SPECIAL STUDY
TOO2P5.O	SPECIAL STUDY
TOO3P5.O	SPECIAL STUDY
TOO4P5.O	SPECIAL STUDY
TOO5P5.O	SPECIAL STUDY
TOO6P5.O	SPECIAL STUDY
TOO7P5.O	SPECIAL STUDY
TOO8P5.O	SPECIAL STUDY
TOO9P5.O	SPECIAL STUDY
TO1OP5.O	SPECIAL STUDY
TO11P5.O	SPECIAL STUDY
TO12P5.O	SPECIAL STUDY
TO13P5.O	SPECIAL STUDY
TO14P5.O	SPECIAL STUDY
TO15P5.O	SPECIAL STUDY
TO16P5.O	SPECIAL STUDY
TO17P5.O	SPECIAL STUDY
TO18P5.O	SPECIAL STUDY
TO19P5.O	OSTEOSARCOMA,BLOOD DYSCRASIA,LIVER DEGENERATION
TO2OP5.O	LIVER DEGENERATION, ASCITES + THROMBOCYTOPENIA
TO21P5.O	TOXIC NEPHRITIS + LIVER DEGENERATION
TO23P1.O	SPECIAL STUDY
TO24P1.O	SPECIAL STUDY
TO25P1.O	SPECIAL STUDY
TO26P1.O	SPECIAL STUDY
TO27P3.O	SPECIAL STUDY
TO28P1.O	SPECIAL STUDY
TO29P3.O	SPECIAL STUDY
TO3OP1.O	SPECIAL STUDY
TO31P3.O	SPECIAL STUDY
TO32P1.O	SPECIAL STUDY
TO33P1.O	SPECIAL STUDY
TO34P1.O	SPECIAL STUDY
TO35P3.O	SPECIAL STUDY

B. PLUTONIUM - 239 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
TO36P1.O	544	10.4	0.0158	15 9 61		5	<1
TO37P1.O	542	8.59	0.0148	15 9 61		186	5
TO38P3.O	489	7.96	0.304	15 9 61		187	98
TO39P1.O	1534	10.7	0.0151	15 9 61		376	9
TO4OP1.O	1534	9.92	0.0177	15 9 61		769	20
TO41P5.O	543	8.50	3.01	30 11 64		1227	6156
TO42P5.O	510	11.4	2.40	10 2 65		13	55
TO43P5.OH	600	14.0	2.86	15 7 65		40	203
TO44P5.OH	517	12.0	2.72	21 9 65		35	169
TO45P5.OH	420	12.3	2.98	28 10 65		5/24	1
TO46P5.O	420	11.90	3.01	28 10 65		732	3747
TO47P5.O	806	12.4	3.02	30 11 65		69	368
TO48P5.O	554	8.5	2.61	11 3 66		1327	5754
TO49P1.O	103	5.00	0.0162	5 7 66	4652		
TO5OP3.O	103	5.30	0.296	5 7 66		2835	1175
TO51P5.O	104	4.80	2.73	6 7 66		1055	4831
TO52P4.O	437	11.8	0.949	7 7 67		14	24
TO53P5.O	1517	13.9	2.82	11 3 69		1559	7016
TO54P5.O	906	11.3	2.77	11 3 69		404	1936
TO55P4.O	445	10.6	0.785	3 6 69		14	20
TO56P5.5	501	11.2	3.73	29 7 69		7	46
TO57P2.OE	618	49.4	0.0961	10 9 69		1506	181
TO58P3.OE	573	52.3	0.291	10 9 69		917	421
TO59P3.OE	591	44.5	0.290	5 11 69		973	442
TO6OP3.OE	567	45.2	0.314	6 1 70		784	393
TO61P2.OE	581	47.2	0.0983	6 1 70		1639	198
TO62P2.OE	583	52.5	0.156	22 1 70		1223	251
TO63P5.O	581	9.13	2.77	14 12 70		490	2337

B. PLUTONIUM - 239 *

DOG NUMBER	COMMENTS ON DEAD DOGS
TO36P1.O	SPECIAL STUDY
TO37P1.O	SPECIAL STUDY
TO38P3.O	SPECIAL STUDY
TO39P1.O	SPECIAL STUDY
TO4OP1.O	SPECIAL STUDY
TO41P5.O	PURPURA HEMORRHAGICA;AUTOHEMAGGLUTINATION;LIVER DEGENERATN
TO42P5.O	SPECIAL STUDY
TO43P5.OH	SPECIAL STUDY
TO44P5.OH	SPECIAL STUDY
TO45P5.OH	SPECIAL STUDY
TO46P5.O	LIVER DEGENERATION
TO47P5.O	SPECIAL STUDY
TO48P5.O	UNDIFFERENTIATED SARCOMA (BONE)
TO49P1.O	
TO5OP3.O	OSTEOSARCOMA
TO51P5.O	OSTEOSARCOMA
TO52P4.O	SPECIAL STUDY
TO53P5.O	LIVER DEGENERATION; ADRENALECTOMY
TO54P5.O	SPECIAL STUDY
TO55P4.O	SPECIAL STUDY
TO56P5.5	SPECIAL STUDY
TO57P2.OE	OSTEOSARCOMA
TO58P3.OE	OSTEOSARCOMA
TO59P3.OE	OSTEOSARCOMA
TO6OP3.OE	OSTEOSARCOMA
TO61P2.OE	OSTEOSARCOMA
TO62P2.OE	OSTEOSARCOMA
TO63P5.O	SPECIAL STUDY

B. PLUTONIUM - 239 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
TO64PO.O							
TO65P4.OP	542	11.5	0.904	30 11 71		14	2
TO66P4.OP	542	10.6	0.913	30 11 71		1184	
TO67P4.OP	539	10.4	0.907	30 11 71		1148	
TO68P1.OE	569	44.2	0.0158	20 4 72		2393	42
TO69P1.OE	569	32.0	0.0160	20 4 72	2536		
TO7OP1.OE	588	40.6	0.0152	9 5 72	2517		
TO71PO.5E	588	48.9	0.00521	9 5 72	2517		
TO72PO.5E	611	44.5	0.00512	1 6 72	2494		
TO73PO.5E	611	38.8	0.00507	1 6 72	2494		
TO74P4.O	3694	7.73	0.937	28 3 73		705	1096
TO75P4.O	3478	8.47	0.897	28 3 73		1451	2058
TO76P4.O	3413	10.7	0.894	28 3 73		1357	1928
TO77P3.O	3413	9.95	0.310	28 3 73		1623	748
TO78P3.O	2488	8.21	0.320	28 3 73		1633	777
TO79PO.5	483	11.1	0.00523	5 6 73		134	2
TO8OPO.2E	569	48.7	0.00153	25 7 73	2075		
TO81PO.2E	569	44.3	0.00157	25 7 73	2075		
TO82PO.2E	597	47.2	0.00191	22 8 73	2047		
TO83PO.1E	575	51.3	0.00061	22 8 73	2047		
TO84PO.1E	517	55.7	0.00066	19 2 75	1501		
TO85PO.1E	557	52.0	0.00071	1 4 75	1460		
TO86P4.OE	525	46.0	0.903	27 2 75		901	1330
TO87P5.O	3008	10.1	2.93	24 2 75		182	936
TO88P5.O	2194	9.80	3.01	24 2 75		184	972
TO89P1.O	490	8.99	0.0176	6 5 75		379	11
TO9OPO.O	487	7.60		6 5 75		378	
TO91P1.O	488	10.6	0.0134	13 5 75		7	<1
TO92P1.O	488	10.8	0.0134	13 5 75		29	<1
TO93P1.O	488	9.04	0.0144	13 5 75		133	3

B. PLUTONIUM - 239 *

DOG NUMBER	COMMENTS ON DEAD DOGS
TO64PO.O	REASSIGNED, SEE T124P1.7
TO65P4.OP	SPECIAL STUDY
TO66P4.OP	FIBROSARCOMA (VERTEBRA)
TO67P4.OP	OSTEOSARCOMA
TO68P1.OE	OSTEOSARCOMA
TO69P1.OE	
TO7OP1.OE	
TO71PO.5E	
TO72PO.5E	
TO73PO.5E	
TO74P4.O	UNDIFFERENTIATED MALIGNANCY (NON-SKELETAL)
TO75P4.O	OSTEOSARCOMA
TO76P4.O	OSTEOSARCOMA
TO77P3.O	OSTEOSARCOMA
TO78P3.O	OSTEOSARCOMA
TO79PO.5	SPECIAL STUDY
TO8OPO.2E	
TO81PO.2E	
TO82PO.2E	
TO83PO.1E	
TO84PO.1E	
TO85PO.1E	
TO86P4.OE	OSTEOSARCOMA
TO87P5.O	SPECIAL STUDY
TO88P5.O	SPECIAL STUDY
TO89P1.O	SPECIAL STUDY
TO9OPO.O	SPECIAL STUDY
TO91P1.O	SPECIAL STUDY
TO92P1.O	SPECIAL STUDY
TO93P1.O	SPECIAL STUDY

B. PLUTONIUM - 239 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
T094P1.0	500	11.1	0.0166	28	5	75		27	<1
T095P1.0	511	9.46	0.0178	5	6	75		60	2
T096P1.0	501	10.9	0.0159	8	7	75		7	<1
T097P1.0	490	13.0	0.0164	10	6	75		211	6
T098P1.0	490	11.5	0.0162	10	6	75		209	6
T099P1.0	497	10.9	0.0151	17	6	75		15	<1
T100P1.0	487	13.0	0.0155	24	6	75		363	9
T101P1.0	490	10.0	0.0158	22	8	75		56	2
T102P1.0	494	11.7	0.0152	26	8	75		140	4
T103P1.0	490	8.97	0.0157	5	9	75		14	<1
T104P1.7	565	7.75	0.0477	16	1	76		11	1
T105PO.0	574	11.8		23	2	76		11	
T106P1.7	585	8.84	0.0455	6	2	76		3	<1
T107P1.7	581	9.35	0.0451	6	2	76		7	<1
T108PO.0	582	10.3		6	2	76		14	
T109PO.0	581	8.50		13	2	76		4	
T110PO.0	579	9.31		12	2	76		7	
T111P1.7	578	8.56	0.0433	11	2	76		14	1
T112P1.7	589	8.90	0.0435	23	2	76		4	<1
T113P1.7	548	10.6	0.0438	19	2	76		18	1
T114PO.0	555	9.25		26	2	76		18	
T115PO.0	570	13.2		12	3	76		4	
T116P5.5	533	8.72	4.32	13	1	76		2	15
T117P2.OY	96	3.79	0.108	15	1	76		7	1
T118P2.OY	96	3.87	0.105	15	1	76		14	3
T119P2.OY	84	4.42	0.0922	15	1	76		28	5
T120P2.OY	96	4.85	0.0840	15	1	76		56	8
T121P2.OY	84	3.64	0.112	15	1	76		119	2
T122P2.OY	96	3.69	0.110	15	1	76		89	3
T123P2.0	2366	10.5	0.0882	15	1	76		14	2
T124P1.7	2558	7.68	0.0527	13	5	76		118	8
T125P2.ON	2	0.32	0.127	22	6	76		3	1
T126P2.ON	2	0.29	0.160	22	6	76		3	1

B. PLUTONIUM - 239 *

DOG NUMBER	COMMENTS ON DEAD DOGS
TO94P1.O	SPECIAL STUDY
TO95P1.O	SPECIAL STUDY
TO96P1.O	SPECIAL STUDY
TO97P1.O	SPECIAL STUDY
TO98P1.O	SPECIAL STUDY
TO99P1.O	SPECIAL STUDY
T1OOP1.O	SPECIAL STUDY
T1O1P1.O	SPECIAL STUDY
T1O2P1.O	SPECIAL STUDY
T1O3P1.O	SPECIAL STUDY
T1O4P1.7	SPECIAL STUDY
T1O5PO.O	SPECIAL STUDY
T1O6P1.7	SPECIAL STUDY
T1O7P1.7	SPECIAL STUDY
T1O8PO.O	SPECIAL STUDY
T1O9PO.O	SPECIAL STUDY
T11OPO.O	SPECIAL STUDY
T111P1.7	SPECIAL STUDY
T112P1.7	SPECIAL STUDY
T113P1.7	SPECIAL STUDY
T114PO.O	SPECIAL STUDY
T115PO.O	SPECIAL STUDY
T116P5.5	SPECIAL STUDY
T117P2.OY	SPECIAL STUDY
T118P2.OY	SPECIAL STUDY
T119P2.OY	SPECIAL STUDY
T12OP2.OY	SPECIAL STUDY
T121P2.OY	SPECIAL STUDY
T122P2.OY	SPECIAL STUDY
T123P2.O	SPECIAL STUDY
T124P1.7	SPECIAL STUDY
T125P2.ON	SPECIAL STUDY
T126P2.ON	SPECIAL STUDY

B. PLUTONIUM - 239 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
T127P2.ON	2	0.31	0.148	19 7 76		1	1
T128P2.ON	2	0.30	0.153	19 7 76		1	1
T129P2.ON	2	0.28	0.197	19 7 76		1	1
T130P4.OP	609	9.66	0.569	18 11 76		60	7
T131P4.OP	609	12.6	0.844	18 11 76	863		
T132P4.OP	609	10.1	0.850	18 11 76		132	16
T133P4.OP	609	9.95	0.844	18 11 76	863		
T134P4.OP	609	9.87	0.832	18 11 76	863		
T135P4.OP	609	11.3	0.577	18 11 76		69	8
T136P4.OP	603	10.2	0.842	18 11 76	863		
T137P4.OP	609	11.4	0.572	18 11 76		257	
T138P4.OP	603	9.66	0.831	18 11 76		138	
T139P4.OP	609	12.2	0.576	18 11 76		417	
T140P4.OP	603	9.79	0.574	18 11 76		824	
T141P4.OP	602	10.3	0.834	18 11 76		40	6
T142P4.OP	602	8.28	0.834	18 11 76		33	4
T143P4.OP	603	10.2	0.842	18 11 76	863		
T144P4.OP	602	9.82	0.836	18 11 76	863		
T145P4.OP	603	10.0	0.575	18 11 76		117	23
T146P4.OP	602	9.63	0.570	18 11 76		124	26
T147P4.OP	597	11.0	0.848	18 11 76	863		
T148P4.OP	602	9.67	0.581	18 11 76		250	
T149P4.OP	597	9.86	0.833	18 11 76	863		
T150P4.OP	597	9.84	0.571	18 11 76		424	
T151P4.OP	597	11.4	0.572	18 11 76		831	
T152P4.OP	597	8.90	0.833	18 11 76	863		
T153P5.O	803	12.0	2.55	16 11 76		22	100
T154P2.ON	2	0.20	0.154	9 11 76		7	1
T155P2.ON	2	0.20	0.151	9 11 76		7	1
T156P2.ON	2	0.28	0.0897	9 11 76		7	1
T157P4.OP	609	11.2	0.833	18 11 76	863		
T158P2.O	695	9.68	0.0866	11 1 77		14	1
T159P2.O	700	10.7	0.0783	11 1 77		14	1
T160P2.O	689	8.71	0.0962	11 1 77		14	1
T161P2.O	700	10.4	0.0806	11 1 77		14	1
T162P2.O	686	9.59	0.0874	11 1 77		14	2
T163P2.O	686	10.6	0.0791	11 1 77		14	2
T164P2.O	686	10.0	0.0838	11 1 77		14	1

B. PLUTONIUM - 239 *

DOG NUMBER	COMMENTS ON DEAD DOGS
T127P2.ON	SPECIAL STUDY
T128P2.ON	SPECIAL STUDY
T129P2.ON	SPECIAL STUDY
T130P4.OP	SPECIAL STUDY
T131P4.OP	
T132P4.OP	SPECIAL STUDY
T133P4.OP	
T134P4.OP	
T135P4.OP	SPECIAL STUDY
T136P4.OP	
T137P4.OP	SPECIAL STUDY
T138P4.OP	SPECIAL STUDY
T139P4.OP	SPECIAL STUDY
T140P4.OP	SPECIAL STUDY
T141P4.OP	SPECIAL STUDY
T142P4.OP	SPECIAL STUDY
T143P4.OP	
T144P4.OP	
T145P4.OP	SPECIAL STUDY
T146P4.OP	SPECIAL STUDY
T147P4.OP	
T148P4.OP	SPECIAL STUDY
T149P4.OP	
T150P4.OP	SPECIAL STUDY
T151P4.OP	SPECIAL STUDY
T152P4.OP	
T153P5.O	SPECIAL STUDY
T154P2.ON	SPECIAL STUDY
T155P2.ON	SPECIAL STUDY
T156P2.ON	SPECIAL STUDY
T157P4.OP	
T158P2.O	SPECIAL STUDY
T159P2.O	SPECIAL STUDY
T160P2.O	SPECIAL STUDY
T161P2.O	SPECIAL STUDY
T162P2.O	SPECIAL STUDY
T163P2.O	SPECIAL STUDY
T164P2.O	SPECIAL STUDY

B. PLUTONIUM - 239 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
T165P2.0	695	10.4	0.0806	11	1	77		14	1
T166P2.0	707	9.27	0.0904	1	2	77		14	1
T167P2.0	707	12.6	0.0665	1	2	77		14	1
T168P2.0	707	9.39	0.0893	1	2	77		14	1
T169P2.0	699	10.9	0.0769	1	2	77		14	1
T170P2.0	699	10.8	0.0776	1	2	77		14	2
T171P2.0	710	11.3	0.0742	1	2	77		14	2
T172P2.0	699	9.79	0.0856	1	2	77		14	1
T173P2.0	707	10.4	0.0806	1	2	77		14	1
T174P2.0Y	93	3.52	0.0989	8	2	77	781		
T175P2.0Y	93	3.14	0.0936	8	2	77		512	44
T176P2.0Y	93	2.89	0.0953	8	2	77		360	
T177P2.0Y	92	4.01	0.0981	8	2	77		364	
T178P2.0Y	92	4.34	0.0969	8	2	77		513	46
T179P2.0Y	92	3.60	0.0967	8	2	77		669	54
T180P0.0	502	9.78		24	2	77		27	
T181P1.0	518	8.44	0.0162	24	3	77		33	2
T182P0.0	518	8.52		24	3	77		56	
T183P0.0	516	11.3		14	4	77		28	
T184P1.0	516	9.60	0.0168	14	4	77		56	2
T185P2.0Y	90	3.31	0.0941	9	3	78		182	20
T186P2.0Y	88	3.71	0.0918	9	5	78		86	11
T187P2.0Y	93	3.20	0.0994	21	11	78		28	4
T188P2.0Y	88	3.32	0.0988	21	11	78		128	14
T198P5.5	1560	7.92	4.57	10	4	78		2	16
T199P5.5	1337	10.7	4.54	10	4	78		2	16
T200P5.5	657	10.9	4.34	13	6	77		2	31
T201P0.0	576	8.95		4	10	77		29	
T202P1.0	586	7.67	0.0173	12	10	77		27	1
T203P2.0	607	10.9	0.0826	5	9	78		7	1
T204P2.0	563	7.70	0.117	6	9	78		7	1
T205P2.0	520	9.55	0.0943	7	9	78		7	1
T206P2.0	1282	11.2	0.0804	24	8	78		7	1
T207P2.0	942	9.20	0.0979	24	8	78		7	1

B. PLUTONIUM - 239 *

DOG NUMBER	COMMENTS ON DEAD DOGS
T165P2.O	SPECIAL STUDY
T166P2.O	SPECIAL STUDY
T167P2.O	SPECIAL STUDY
T168P2.O	SPECIAL STUDY
T169P2.O	SPECIAL STUDY
T17OP2.O	SPECIAL STUDY
T171P2.O	SPECIAL STUDY
T172P2.O	SPECIAL STUDY
T173P2.O	SPECIAL STUDY
T174P2.OY	
T175P2.OY	SPECIAL STUDY
T176P2.OY	SPECIAL STUDY
T177P2.OY	SPECIAL STUDY
T178P2.OY	SPECIAL STUDY
T179P2.OY	SPECIAL STUDY
T18OPO.O	SPECIAL STUDY
T181P1.O	SPECIAL STUDY
T182PO.O	SPECIAL STUDY
T183PO.O	SPECIAL STUDY
T184P1.O	SPECIAL STUDY
T185P2.OY	SPECIAL STUDY
T186P2.OY	SPECIAL STUDY
T187P2.OY	SPECIAL STUDY
T188P2.OY	SPECIAL STUDY
T198P5.5	SPECIAL STUDY
T199P5.5	SPECIAL STUDY
T2OOP5.5	SPECIAL STUDY
T2O1PO.O	SPECIAL STUDY
T2O2P1.O	SPECIAL STUDY
T2O3P2.O	SPECIAL STUDY
T2O4P2.O	SPECIAL STUDY
T2O5P2.O	SPECIAL STUDY
T2O6P2.O	SPECIAL STUDY
T2O7P2.O	SPECIAL STUDY

B. PLUTONIUM - 239 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
T208P2.0	942	10.9	0.0827	24	8	78		7	1
T209P2.0	940	9.80	0.0919	24	8	78		7	1
T210P2.0	920	9.25	0.0974	24	8	78		7	1
T211P2.0	1295	7.40	0.122	23	8	78		8	2
T212P2.0	802	8.80	0.103	21	8	78		10	2
T213P2.OW	549	9.50	0.0703	10	10	78		7	1
T214P2.OW	549	9.00	0.0742	10	10	78		7	2
T215P2.OW	549	8.60	0.0777	10	10	78		7	1
T216P2.OW	533	11.4	0.0586	10	10	78		7	1
T217P2.OW	533	9.40	0.0711	10	10	78		7	1
T218P1.OW	611	10.2	0.0116	25	10	78		7	1
T219P2.OW	904	12.0	0.0731	1	12	78		32	10
T220P2.OW	904	11.3	0.0776	1	12	78		42	14
T221P2.OW	806	9.36	0.0938	1	12	78		35	14
T222P5.OY	91	3.08	3.27	15	1	79		7	40
T223P5.OY	91	2.18	2.77	15	1	79		7	23
T224P5.OY	91	2.55	3.23	15	1	79		14	50
T225P5.OY	91	2.08	2.72	15	1	79		14	50

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* T22P0.0 had been reassigned and is now F06T0.0A
T043P5.OH was also given 1.01 uCi 239Pu/kg one day prior to sacrifice
T044P5.OH was given 0.833 uCi 239Pu /kg and about 9.17 uCi 59Fe/kg one day prior to sacrifice.

Dogs in the above tabulation having the letter E as the final entry in the "DOG NUMBER" column are St. Bernards. Those having the letter P in that position were given plutonium in particulate form.

T117 . . . T122P2Y and T123P2 were given tracer 237Pu in the same solution containing their 239Pu.

Dogs in the sequence T213P2.OW . . . T221P2.OW were given a mixture of 239Pu, 237Pu and 241Am in their injection solution.

B. PLUTONIUM - 239 *

DOG NUMBER	COMMENTS ON DEAD DOGS
T208P2.0	SPECIAL STUDY
T209P2.0	SPECIAL STUDY
T210P2.0	SPECIAL STUDY
T211P2.0	SPECIAL STUDY
T212P2.0	SPECIAL STUDY
T213P2.0W	SPECIAL STUDY
T214P2.0W	SPECIAL STUDY
T215P2.0W	SPECIAL STUDY
T216P2.0W	SPECIAL STUDY
T217P2.0W	SPECIAL STUDY
T218P1.0W	SPECIAL STUDY
T219P2.0W	SPECIAL STUDY
T220P2.0W	SPECIAL STUDY
T221P2.0W	SPECIAL STUDY
T222P5.0Y	SPECIAL STUDY
T223P5.0Y	SPECIAL STUDY
T224P5.0Y	SPECIAL STUDY
T225P5.0Y	SPECIAL STUDY

C. RADIUM - 228 (MESOTHORIUM) *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79 DEATH	DOSE TO SKELETON (RADS)
TOO1M4.5	529	9.13	4.23	8 9 54	314	2131
TOO2M4.5	463	8.93	4.27	8 9 54	755	6796
TOO3M5.O	579	9.15	10.6	13 3 56	700	21156

* (uCi 228Th/uCi 228Ra) injected = O.O3.

C. RADIUM - 228 (MESOTHORIUM) *

DOG NUMBER	COMMENTS ON DEAD DOGS
TOO1M4.5	CANINE DISTEMPER
TOO2M4.5	SPECIAL STUDY
TOO3M5.O	ULCERATIVE GINGIVITIS, SEVERE ANEMIA + CRIPPLING FRACTURE

D. THORIUM - 228 (RADIOTHORIUM) *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79 DEATH	DOSE TO SKELETON (RADS)
TO01T5.0	607	9.30	4.88	1 12 53	23	1548
TO02T5.0	501	8.48	2.56	8 2 54	77	2639
TO03T4.0	429	10.4	0.870	8 2 54	820	6504
TO04T5.0	455	8.92	2.59	28 9 54	113	3844
TO05T5.0	455	10.1	2.32	28 9 54	65	2032
TO06T4.0	591	7.01	0.884	18 10 55	651	5697
TO07T3.0	591	9.23	0.298	18 10 55	910	2369
TO08T3.0	606	9.23	0.293	14 10 58	1043	2511
TO09T3.0	447	11.0	0.285	4 2 59	1	4
TO10T3.0	447	14.2	0.289	4 2 59	8	32
TO11T3.0	500	8.62	0.335	16 6 59	22	101
TO12T3.0	514	10.6	0.302	7 7 59	22	92
TO13T3.0	754	13.1	0.298	28 7 59	22	91

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* T11, 12, 13T3 recieved 40, 4, and 0.4 mg. 232Th, respectively

D. THORIUM - 228 (RADIOTHORIUM) *

DOG NUMBER	COMMENTS ON DEAD DOGS
T001T5.0	DIED, SPECIAL STUDY
T002T5.0	SPECIAL STUDY
T003T4.0	CRIPPLING FRACTURES + NEPHRITIS
T004T5.0	THROMBOCYTOPENIA + PURPURA
T005T5.0	NEPHRITIS, THROMBOCYTOPENIA + PURPURA
T006T4.0	CRIPPLING FRACTURES
T007T3.0	SPECIAL STUDY
T008T3.0	OSTEOSARCOMA
T009T3.0	SPECIAL STUDY
T010T3.0	SPECIAL STUDY
T011T3.0	SPECIAL STUDY
T012T3.0	SPECIAL STUDY
T013T3.0	SPECIAL STUDY

E. STRONTIUM - 90 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D	MO	YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
TO01S0.0	151	7.71		5	3	54	112		
TO02S5.0	149	6.85	148.	5	3	54	18		835
TO03S5.0	144	6.19	148.	5	3	54	28		1276
TO04S5.0	151	7.05	148.	5	3	54	41		2593
TO05S5.0	144	5.25	148.	5	3	54	116		6484
TO06S5.0	155	7.01	87.0	16	3	54	1/24		3
TO07S5.0	155	6.74	87.0	16	3	54	2		112
TO08S0.0	243	7.00		4	11	54	1/24		
TO08S2.0H	67	3.69	2.74	27	9	55	66		41
TO09S2.0H	67	2.79	3.62	27	9	55	66		53
TO10S2.0H	67	3.11	3.25	27	9	55	132		124
TO11S2.0H	67	3.85	2.62	27	9	55	132		100
TO12S3.0	593	10.6	10.5	11	9	57	5		20
TO13S4.0	324	10.5	19.1	8	7	60	8		67
TO14S5.0	542	10.0	96.1	7	11	61	9		233
TO15S5.0	595	9.43	98.4	7	11	61	30		564
TO16S2.0	604	9.71	3.27	8	11	61	9		8
TO17S6.0	670	7.18	295.	19	1	62	14		919
TO18S6.0	670	5.94	302.	19	1	62	1369		25217
TO19S6.0	670	5.43	284.	19	1	62	23		849
TO20S4.0J	440	8.54	28.9	2	10	63	13		104
TO21S2.5J	363	7.20	8.3	2	10	63	13		191
TO22S5.0	545	9.01	99.0	1	4	69	1525		11690
TO23S5.0	545	11.6	100.	1	4	69	1379		14121

*

TO8 . . . 11S2.0H were given 10 injections, 1 uCi each at weekly intervals. Age is at first injection, wt. is average during the injection period, uCi/kg is total 90Sr/average weight, date is at first injection. days are from first injection to death, and dose is computed from mid-injection to death.

E. STRONTIUM 90 *

DOG NUMBER	COMMENTS ON DEAD DOGS
T001S0.0	SPECIAL STUDY
T002S5.0	SPECIAL STUDY
T003S5.0	SPECIAL STUDY
T004S5.0	SPECIAL STUDY
T005S5.0	SPECIAL STUDY
T006S5.0	SPECIAL STUDY
T007S5.0	SPECIAL STUDY
T008S0.0	SPECIAL STUDY
T008S2.0H	SPECIAL STUDY
T009S2.0H	SPECIAL STUDY
T010S2.0H	SPECIAL STUDY
T011S2.0H	SPECIAL STUDY
T012S3.0	BREMSSTRAHLUNG PHANTOM
T013S4.0	BREMSSTRAHLUNG PHANTOM SAM MCGEE
T014S5.0	SPECIAL STUDY
T015S5.0	SPECIAL STUDY
T016S2.0	SPECIAL STUDY
T017S6.0	LEUKOPENIA, THROMBOCYTOPENIA + PURPURA
T018S6.0	HEMANGIOSARCOMA (ISCHIUM)
T019S6.0	LEUKOPENIA, THROMBOCYTOPENIA + PURPURA
T020S4.0J	SPECIAL STUDY
T021S2.5J	SPECIAL STUDY
T022S5.0	HEMANGIOSARCOMA (BONE)
T023S5.0	OSTEOSARCOMA

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* T20S4J received 0.5 uCi 85Sr in addition to the 246.8 uCi 90Sr

T21S2.5J recieved 0.5 uCi 85Sr and 600 uCi 89Sr in addition to the 59.8 uCi 90Sr.

F. RADIUM - 224 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
T001Q3.0J	460	9.55	0.875	26 3 63		4/24	1
T002Q4.0	466	12.0	2.91	27 3 63		2317	937
T003Q4.0	466	13.1	2.91	27 3 63		2708	1017
T004Q5.0	480	9.55	9.71	24 4 63		1462	4951
T005Q5.0	455	9.67	9.59	24 4 63		1638	5236
T006Q6.0	455	8.29	21.4	17 10 63		13	1137
T007Q5.0	465	11.8	8.56	6 11 63		2053	604
T008Q5.0	475	9.77	8.62	6 11 63		16	450
T009Q4.0	503	9.80	2.57	4 12 63		1451	156
T010Q4.0	503	10.3	2.57	4 12 63		262	144
T011Q3.0	495	9.10	0.885	4 12 63		3668	56
T012Q3.0	495	13.5	0.889	4 12 63		4087	56
T013Q3.0	495	11.3	0.912	4 12 63		4605	58
T014Q3.0	438	10.3	0.870	4 12 63		4785	55
T015Q4.0	515	12.7	2.73	1 2 68		1692	3881
T016Q2.0	515	9.36	0.310	1 2 68		3757	650
T017Q2.0	515	10.2	0.311	1 2 68	4076		
T018Q2.0	502	9.68	0.306	1 2 68	4076		
T019Q1.0	515	11.8	0.0475	1 2 68	4076		
T020Q1.0	515	10.4	0.0472	1 2 68	4076		
T021Q1.0	502	9.08	0.0447	1 2 68	4076		
T022Q5.0	643	8.39	10.1	13 12 77		3/24	7
T023Q5.0	619	10.9	8.37	3 1 78		1/24	1
T024Q5.0	649	9.14	10.1	19 12 77		1	63
T025Q5.0	638	8.78	10.1	10 1 78		8/24	17
T026Q5.0	685	8.81	9.98	24 1 78		7	309
T027Q5.0	642	10.6	10.1	14 1 78		3	148

*The skeletal doses in rads are from ^{224}Ra (and daughters) plus contamination from ^{210}Pb and ^{228}Th. In some cases the ^{210}Pb and ^{228}Th contamination was appreciable. Please see the article, "^{224}Ra toxicity from a pilot study in beagles" in COO-119-252, March 1977, pp. 272-287, particularly see p. 278.

T001Q3.0J also received 18.0 µCi ^{85}Sr.

**Skeletal doses in rads for T22Q5 to T27Q5 are from ^{224}Ra (and daughters). Contamination of the injection solution with other emitters was negligible. Dosimetric details are to be found in COO-119-253, pp. 263-276, March 1978.

F. RADIUM - 224 (QUICKRADIUM) *

DOG NUMBER	COMMENTS ON DEAD DOGS
TO01Q3.0J	SPECIAL STUDY
TO02Q4.0	OSTEOSARCOMA
TO03Q4.0	HEMANGIOSARCOMA (ILIUM)
TO04Q5.0	OSTEOSARCOMA, EPIDERMOID CARCINOMA (FRONTAL SINUS)
TO05Q5.0	OSTEOSARCOMA
TO06Q6.0	PURPURA HEMORRHAGICA
TO07Q5.0	OSTEOSARCOMA
TO08Q5.0	PURPURA HEMORRHAGICA
TO09Q4.0	STRANGULATION ON VOMITUS AND GRAND MAL
TO10Q4.0	STATUS EPILEPTICUS
TO11Q3.0	AORTIC BODY TUMOR
TO12Q3.0	AORTA THROMBO-EMBOLISM
TO13Q3.0	CIRCULATORY FAILURE
TO14Q3.0	NEPHRITIS
TO15Q4.0	OSTEOSARCOMA
TO16Q2.0	OSTEOSARCOMA
TO17Q2.0	
TO18Q2.0	
TO19Q1.0	
TO20Q1.0	
TO21Q1.0	
TO22Q5.0	SPECIAL STUDY
TO23Q5.0	SPECIAL STUDY
TO24Q5.0	SPECIAL STUDY
TO25Q5.0	SPECIAL STUDY
TO26Q5.0	SPECIAL STUDY
TO27Q5.0	SPECIAL STUDY

G. AMERICIUM - 241 *

DOG NUMBER	INJECTION AGE (DAYS)	INJECTION WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DAYS SINCE INJECTION DEATH	DOSE TO SKELETON (RADS)
TO15W5.5	858	11.5	4.53	23 10 67		1	6
TO16W5.O	461	10.7	2.78	29 1 68		20	66
TO32W5.5	553	11.O	4.46	30 4 68		7	36
TO33W5.5	393	10.5	4.47	30 4 68		8	44
TO56W5.O	552	11.3	2.90	25 11 69		15	65
TO57W5.O	496	7.01	2.77	26 1 70		15	56
TO99W5.O	547	11.3	2.67	10 11 70		252	966
T101W5.O	399	10.4	2.98	17 8 72		1	4
T102W3.O	515	11.6	O.280	10 10 72		17	7
T103W3.O	501	10.6	O.283	10 10 72	2363		
T104W3.O	2658	7.67	O.305	28 11 72		1864	701
T105W3.O	2224	7.78	O.301	28 11 72		1100	647
T106W3.O	2224	13.8	O.308	28 11 72		1909	791
T107W5.O	3543	9.24	2.34	2 4 73		36	110
T108W3.O	507	12.6	O.304	8 8 73	2061		
T109W3.O	506	9.90	O.306	8 8 73	2061		
T110W3.O	506	9.30	O.306	8 8 73		1506	341
T111W3.O	506	9.81	O.303	8 8 73	2061		
T112W3.O	506	6.92	O.333	23 10 73		44	19
T113W3.O	499	9.35	O.333	23 10 73	1985		
T114W3.O	531	12.9	O.300	2 7 74		1505	667
T117W4.O	385	9.98	1.20	19 11 74		1416	2680
T118W4.O	385	8.96	1.34	19 11 74	1593		
T119W4.O	385	8.36	1.44	19 11 74	1593		
T120W5.O	2894	8.77	3.17	24 2 75		283	1376
T142W3.O	586	9.76	O.299	28 1 76	1158		
T143W3.O	533	9.21	O.317	4 2 76	1151		
T144W4.O	397	11.8	O.804	19 5 76		545	697
T145W4.O	397	11.6	O.983	19 5 76		545	852
T146W3.O	593	7.07	O.301	13 2 76	1142		
T147W5.ON	1	O.25	3.11	1 2 76		1	6
T148W5.ON	1	O.26	2.97	1 2 76		3	21

G. AMERICIUM - 241 *

DOG NUMBER	COMMENTS ON DEAD DOGS
TO15W5.5	SPECIAL STUDY
TO16W5.O	SPECIAL STUDY
TO32W5.5	SPECIAL STUDY
TO33W5.5	SPECIAL STUDY
TO56W5.O	SPECIAL STUDY
TO57W5.O	SPECIAL STUDY
TO99W5.O	SPECIAL STUDY
T1O1W5.O	SPECIAL STUDY
T1O2W3.O	SPECIAL STUDY
T1O3W3.O	
T1O4W3.O	EMPYEMA
T1O5W3.O	FIBROSARCOMA (ORAL); KIDNEY DEGENERATION
T1O6W3.O	TRAUMA
T1O7W5.O	MELANOMA (MOUTH)
T1O8W3.O	
T1O9W3.O	
T11OW3.O	ANESTHETIC ACCIDENT; ADRENO-CORTICAL HYPOPLASIA
T111W3.O	
T112W3.O	INTUSSUSCEPTION
T113W3.O	
T114W3.O	OSTEOSARCOMA
T117W4.O	OSTEOSARCOMA
T118W4.O	
T119W4.O	
T12OW5.O	KIDNEY DEGENERATION; LIVER DEGENERATION
T142W3.O	
T143W3.O	
T144W4.O	SPECIAL STUDY
T145W4.O	SPECIAL STUDY
T146W3.O	
T147W5.ON	SPECIAL STUDY
T148W5.ON	SPECIAL STUDY

G. AMERICIUM - 241 *

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
T149W5.ON	1	0.27	2.88	1 2 76		5	33
T150W5.ON	1	0.28	2.79	1 2 76		5	32
T151W5.ON	1	0.24	3.20	1 2 76		1	6
T152W5.ON	1	0.25	3.11	1 2 76		1	7
T153W5.ON	1	0.27	2.84	1 2 76		3	18
T154W3.0	535	9.96	0.287	4 8 76		21	11
T155W3.0	532	10.2	0.280	4 8 76	969		
T156W3.0	528	10.0	0.286	4 8 76	969		
T157W3.0	526	9.99	0.286	4 8 76		23	10
T158W0.0	553	12.9		30 12 76	821		
T159W0.0	546	10.6		30 12 76	821		
T160W1.0	577	11.4	0.0159	30 12 76	821		
T161W1.0	546	11.9	0.0159	30 12 76	821		
T162W1.0	546	9.64	0.0164	30 12 76	821		
T163W1.0	544	9.32	0.0162	30 12 76	821		
T164W1.7	553	11.3	0.0481	30 12 76	821		
T165W1.7	546	8.73	0.0488	30 12 76	821		
T166W1.7	544	9.28	0.0480	30 12 76	821		
T167W1.7	544	9.04	0.0482	30 12 76	821		
T168W4.0	997	9.80	0.976	21 6 78		7	9
T169W4.0	934	10.4	0.919	21 6 78		7	8
T170W4.0	997	10.2	0.937	21 6 78		7	7
T171W4.0	856	9.00	1.06	21 6 78		7	6
T172W4.0	876	11.6	0.824	21 6 78		7	5
T173W4.0	933	11.7	0.817	20 6 78		8	9
T174W4.0	994	8.50	1.12	18 6 78		10	15

G. AMERICIUM - 241 *

DOG NUMBER	COMMENTS ON DEAD DOGS
T149W5.ON	SPECIAL STUDY
T15OW5.ON	SPECIAL STUDY
T151W5.ON	SPECIAL STUDY
T152W5.ON	SPECIAL STUDY
T153W5.ON	SPECIAL STUDY
T154W3.O	SPECIAL STUDY
T155W3.O	
T156W3.O	
T157W3.O	SPECIAL STUDY
T158WO.O	
T159WO.O	
T16OW1.O	
T161W1.O	
T162W1.O	
T163W1.O	
T164W1.7	
T165W1.7	
T166W1.7	
T167W1.7	
T168W4.O	SPECIAL STUDY
T169W4.O	SPECIAL STUDY
T17OW4.O	SPECIAL STUDY
T171W4.O	SPECIAL STUDY
T172W4.O	SPECIAL STUDY
T173W4.O	SPECIAL STUDY
T174W4.O	SPECIAL STUDY

H. LEAD - 210

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79 DEATH	DOSE TO SKELETON (RADS)
TOO1L5.O	522	9.78	1O.7	24 6 69	1497	816O
TOO2L5.O	522	9.16	1O.7	24 6 69	28	3O
TOO3L5.O	522	9.78	1O.7	24 6 69	11OO	695O

H. LEAD - 210

DOG NUMBER	COMMENTS ON DEAD DOGS
TO01L5.0	OSTEOSARCOMA
TO02L5.0	SPECIAL STUDY
TO03L5.0	OSTEOSARCOMA

I. CALIFORNIUM - 252

DOG NUMBER	INJECTION AGE (DAYS)	INJECTION WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DAYS SINCE INJECTION DEATH	DOSE TO SKELETON (RADS)
TOO1F5.O	586	11.4	2.81	8 9 71		36	382
TOO2F5.O	540	10.7	2.87	17 11 71		13	138

I. CALIFORNIUM - 252

DOG NUMBER	COMMENTS ON DEAD DOGS
T001F5.0	SPECIAL STUDY
T002F5.0	SPECIAL STUDY

J. CALIFORNIUM - 249

DOG NUMBER	INJECTION AGE (DAYS)	INJECTION WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DAYS SINCE INJECTION DEATH	DOSE TO SKELETON (RADS)
TOO1G5.O	597	12.2	2.84	24 2 71		500	2728
TOO2G5.O	584	10.7	2.77	24 2 71		7	39
TOO3G5.O	584	9.89	2.80	24 2 71		21	111

J. CALIFORNIUM - 249

DOG NUMBER	COMMENTS ON DEAD DOGS
T001G5.0	NEPHRITIS; MYOCARDIAL INFARCTION
T002G5.0	SPECIAL STUDY
T003G5.0	SPECIAL STUDY

K. CURIUM - 243/244

DOG NUMBER	INJECTION AGE (DAYS)	INJECTION WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79 DEATH	DOSE TO SKELETON (RADS)
TOO1C5.O	511	10.4	2.60	27 2 73	1142	7346
TOO2C5.O	485	12.2	2.64	27 2 73	6	32
TOO3C5.O	485	11.4	2.64	27 2 73	13	69
TOO4C5.O	485	12.5	2.64	27 2 73	20	107
TOO5C5.O	485	12.8	2.63	27 2 73	384	2613
TOO6C5.O	498	10.7	2.90	22 10 73	87	463

K. CURIUM - 243/244

DOG NUMBER	COMMENTS ON DEAD DOGS
TOO1C5.O	KIDNEY DEGENERATION; LIVER DEGENERATION
TOO2C5.O	SPECIAL STUDY
TOO3C5.O	SPECIAL STUDY
TOO4C5.O	SPECIAL STUDY
TOO5C5.O	LIVER DEGENERATION
TOO6C5.O	SPECIAL STUDY

L. EINSTIENIUM - 253

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79	DEATH	DOSE TO SKELETON (RADS)
TOO1E5.O	47O	9.82	2.87	5 6 73		7	33
TOO2E5.O	483	12.2	2.89	5 6 73		21	171
TOO3E5.O	483	11.O	2.84	5 6 73		55	2O1
TOO4E5.O	484	12.3	2.97	6 6 73	2124		
TOO5E5.O	484	11.2	2.93	1O 9 73		7	57

L. EINSTIENIUM - 253

DOG NUMBER	COMMENTS ON DEAD DOGS
T001E5.0	SPECIAL STUDY
T002E5.0	SPECIAL STUDY
T003E5.0	SPECIAL STUDY
T004E5.0	
T005E5.0	SPECIAL STUDY

M. PLUTONIUM - 237

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79 DEATH	DOSE TO SKELETON (RADS)
TOO1K1.O	520	9.53	0.0286	10 12 74	13	1
TOO2K1.O	517	10.3	0.0266	10 12 74	20	1
TOO3K1.O	517	9.72	0.0281	10 12 74	27	1

M. PLUTONIUM - 237

DOG NUMBER	COMMENTS ON DEAD DOGS
TOO1K1.O	SPECIAL STUDY
TOO2K1.O	SPECIAL STUDY
TOO3K1.O	SPECIAL STUDY

N. URANIUM - 233

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79 DEATH	DOSE TO SKELETON (RADS)
TOO1U5.O	539	10.4	2.91	23 2 76	94	45
TOO2U5.O	524	12.O	2.91	11 3 76	726	196
TOO3U5.O	541	11.4	2.42	25 2 76	7	4
TOO4U5.O	541	9.O1	2.91	25 2 76	14	9
TOO5U5.O	541	9.O8	2.96	25 2 76	21	7
TOO6U5.O	509	12.2	2.92	25 2 76	364	192
TOO7U5.O	667	10.4	2.77	10 5 76	1	1

N. URANIUM - 233

DOG NUMBER	COMMENTS ON DEAD DOGS
T001U5.0	SPECIAL STUDY
T002U5.0	SPECIAL STUDY
T003U5.0	SPECIAL STUDY
T004U5.0	SPECIAL STUDY
T005U5.0	SPECIAL STUDY
T006U5.0	SPECIAL STUDY
T007U5.0	SPECIAL STUDY

O. URANIUM - 238

DOG NUMBER	INJECTION AGE (DAYS)	INJECTION WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 31/3/79 DEATH	DOSE TO SKELETON (RADS)
TOO1VO.1	568	11.3	0.0001	16 11 76	865	

O. URANIUM - 238

DOG NUMBER	COMMENTS ON DEAD DOGS
TOO1VO.1	

P. ANICILLARY

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	AGE (DAYS) AS OF 31/3/79 DEATH	DOSE TO SKELETON (RADS)
FO01AO.O					1383	
FO02AO.O					2492	
MO03AO.O					1451	
MO04AO.O					3346	
MO05AO.O					3747	
MO06AO.O					5266	
MO07AO.O					3896	
MO08AO.O					3746	
FO09AO.O					3719	
FO10AO.O					2605	
FO11AO.O					4198	
FO12AO.O					4219	
FO13AO.O					4527	
FO14AO.O					3777	
FO15AO.O					4874	
FO16AO.O					4410	
FO17AO.O					2145	
FO18AO.O					5921	
FO19AO.O					4166	
FO20AO.O					2464	
FO21AO.O					5508	
FO22AO.O					4350	
MO23AO.O					1741	
MO24AO.O					3074	
FO25AO.O					5646	
MO26AO.O					4133	
MO27AO.O					2130	
MO28AO.O					3114	
MO29AO.O					5017	
FO31AO.O					5266	
FO32AO.O					1990	
FO33AO.O					3282	
FO34AO.O					2584	
MO35AO.O					529	
MO36AO.O					1971	
MO37AO.O					4091	
FO38AO.O					3802	
MO39AO.O					4406	
MO40AO.O					4666	
FO41AO.O					4704	
MO42AO.O					1265	
FO43AO.O					3883	
FO44AO.O					5016	

P. ANCILLARY

DOG NUMBER	COMMENTS ON DEAD DOGS
FO01AO.O	SPECIAL STUDY
FO02AO.O	SPECIAL STUDY
MO03AO.O	SPECIAL STUDY
MO04AO.O	NOT DETERMINED (NO BONE TUMOR)
MO05AO.O	TRANSITIONAL CELL CARCINOMA, NEPHRITIS, PNEUMONIA
MO06AO.O	BRAIN HEMORRHAGE
MO07AO.O	LYMPHOSARCOMA
MO08AO.O	PROGRESSIVE PARALYSIS, CAUSE UNKNOWN
FO09AO.O	VAGINAL FIBROMA
FO10AO.O	SPECIAL STUDY
FO11AO.O	MAMMARY CARCINOMA
FO12AO.O	SEVERE OSTEOARTHRITIS
FO13AO.O	SPECIAL STUDY
FO14AO.O	OBTURATING EMBOLISM OF PORTAL VEIN
FO15AO.O	TRANSITIONAL CELL CARCINOMA URINARY BLADDER
FO16AO.O	SPECIAL STUDY
FO17AO.O	TRAUMA
FO18AO.O	NEPHRITIS
FO19AO.O	MAMMARY GLAND CARCINOMA
FO20AO.O	SPECIAL STUDY
FO21AO.O	MAMMARY CARCINOMA; THYROID CARCINOMA
FO22AO.O	LYMPHOSARCOMA
MO23AO.O	OBTURATING PULMONARY EMBOLISM
MO24AO.O	SPECIAL STUDY
FO25AO.O	ISLET CELL TUMOR; PNEUMONIA
MO26AO.O	SEMINOMA
MO27AO.O	SPECIAL STUDY
MO28AO.O	SPECIAL STUDY
MO29AO.O	MELANOMA ORAL CAVITY
FO31AO.O	UNDETERMINED
FO32AO.O	LYMPHOSARCOMA
FO33AO.O	OBTURATING PULMONARY EMBOLISM
FO34AO.O	SPECIAL STUDY
MO35AO.O	SPECIAL STUDY
MO36AO.O	SPECIAL STUDY
MO37AO.O	SPECIAL STUDY
FO38AO.O	MAMMARY CARCINOMA
MO39AO.O	OBTURATING PULMONARY THROMBO EMBOLISM
MO40AO.O	EPIDERMOID CARCINOMA (GINGIVA), PNEUMONIA
FO41AO.O	LEIOMYOSARCOMA (SPLEEN)
MO42AO.O	STATUS EPILEPTICUS
FO43AO.O	SPECIAL STUDY
FO44AO.O	ADRENAL CORTICAL CARCINOMA

P. ANICILLARY

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	AGE (DAYS) AS OF 31/3/79	DEATH	DOSE TO SKELETON (RADS)
FO45AO.O						6182	
FO47AO.O						1732	
FO48AO.O						5075	
FO49AO.O						4773	
MO50AO.O						2264	
FO51AO.O						1089	
FO52AO.O						509	
FO53AO.O						5520	
FO54AO.O						3190	
FO55AO.O						4563	
MO56AO.O						701	
FO57AO.O						4322	
MO58AO.O						767	
MO59AO.O						567	
MO61AO.O						5511	
FO62AO.O						5348	
FO63AO.O						4530	
FO68AO.O						4521	
FO70AO.O						5914	
MO71AO.O						1472	
MO73AO.O						5695	
FO74AO.O						5553	
MO75AO.O						5284	
FO76AO.O						5813	
FO77AO.O						6046	
FO78AO.O						5110	
FO79AO.O						4359	
FO80AO.O						5419	
FO81AO.O						5921	
MO82AO.O						3627	
FO83AO.O						4988	
MO84AO.O						5292	
MO85AO.O						5499	
MO86AO.O						499	
FO87AO.O						4862	
FO88AO.O							
FO89AO.O							
FO90AO.O							
FO91AO.O						4797	
FO92AO.O						4799	
MO93AO.O							
FO94AO.O							
FO95AO.O						4719	

P. ANCILLARY

DOG NUMBER	COMMENTS ON DEAD DOGS
FO45AO.O	PNEUMONIA; SENILITY
FO47AO.O	SPECIAL STUDY
FO48AO.O	CHRONIC PANCREATITIS
FO49AO.O	ISLET CELL TUMOR; BRAIN HEMORRHAGE
MO5OAO.O	SPECIAL STUDY
FO51AO.O	SPECIAL STUDY
FO52AO.O	SPECIAL STUDY
FO53AO.O	THYROID CARCINOMA
FO54AO.O	SPECIAL STUDY
FO55AO.O	NEPHRITIS; METASTATIC CALCIFICATION
MO56AO.O	VOLVULUS + PERITONITIS
FO57AO.O	UNDIFFERENTIATED MALIGNANCY
MO58AO.O	SPECIAL STUDY
MO59AO.O	SPECIAL STUDY
MO61AO.O	FIBROSARCOMA (ABDOMEN)
FO62AO.O	AORTA THROMBO-EMBOLISM
FO63AO.O	MAMMARY CARCINOMA, TRANSITIONAL CELL CARCINOMA
FO68AO.O	UNDIFFERENTIATED CARCINOMA
FO7OAO.O	FIBROSARCOMA (ORAL); NEPHRITIS
MO71AO.O	SPECIAL STUDY
MO73AO.O	DEGENERATION OF ADRENAL GLAND + DIABETES MELLITUS
FO74AO.O	LYMPHO SARCOMA
MO75AO.O	AORTIC THROMBUS
FO76AO.O	EPIDERMOID CARCINOMA (ORAL); THYROID CARCINOMA
FO77AO.O	SENILITY
FO78AO.O	MAMMARY CARCINOMA
FO79AO.O	PNEUMONIA
FO8OAO.O	LUNG CARCINOMA
FO81AO.O	FIBROSARCOMA (ORAL); NEPHRITIS
MO82AO.O	LUNG CARCINOMA
FO83AO.O	SARCOMA (INTESTINE)
MO84AO.O	PEMPHIGUS VULGARIS
MO85AO.O	SENILITY
MO86AO.O	SPECIAL STUDY
FO87AO.O	SPECIAL STUDY
FO88AO.O	REASSIGNED, SEE T1O7W5.O
FO89AO.O	REASSIGNED, SEE TO74P4.O
FO9OAO.O	REASSIGNED, SEE TO75P4.O
FO91AO.O	SPECIAL STUDY
FO92AO.O	SPECIAL STUDY
MO93AO.O	REASSIGNED, SEE TO76P4.O
FO94AO.O	REASSIGNED, SEE TO77P3.O
FO95AO.O	SPECIAL STUDY

P. ANICILLARY

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	AGE (DAYS) AS OF 31/3/79	DEATH	DOSE TO SKELETON (RADS)
F096A0.0						4373	
F097A0.0						4117	
F098A0.0						3752	
F099A0.0						479	
M100A0.0						407	
M101A0.0						290	
F102A0.0						243	
M103A0.0						217	
M104A0.0						188	
F105A0.0						157	
F106A0.0						4325	
F107A0.0						4137	
F108A0.0						1969	
F109A0.0						2253	
F110A0.0							
F111A0.0						2923	
F112A0.0						2942	
F113A0.0							
F114A0.0						2591	
F115A0.0						2057	
F116A0.0							
F117A0.0							
F118A0.0							
F119A0.0							
F120A0.0							
F121A0.0							
F122A0.0							
F123A0.0						375	
F124A0.0							
F125A0.0							
F126A0.0							
F127A0.0							
F128A0.0							
F129A0.0							
F130A0.0					2464		
F131A0.0					2463		
F132A0.0					2419		
F133A0.0					2323		
F134A0.0					2323		
F135A0.0					2299		
M136A0.0					2419		
F137A0.0							
F138A0.0							

P. ANCILLARY

DOG NUMBER	COMMENTS ON DEAD DOGS
FO96AO.O	
FO97AO.O	SPECIAL STUDY
FO98AO.O	MAMMARY CELL CARCINOMA
FO99AO.O	SPECIAL STUDY
M1OOAO.O	SPECIAL STUDY
M1O1AO.O	SPECIAL STUDY
F1O2AO.O	SPECIAL STUDY
M1O3AO.O	SPECIAL STUDY
M1O4AO.O	SPECIAL STUDY
F1O5AO.O	SPECIAL STUDY
F1O6AO.O	SPECIAL STUDY
F1O7AO.O	SPECIAL STUDY
F1O8AO.O	ENCEPHALOMALACIA (BACTERIAL)
F1O9AO.O	METRITIS
F11OAO.O	REASSIGNED, SEE TO78P3.O
F111AO.O	PNEUMONIA
F112AO.O	SPECIAL STUDY
F113AO.O	REASSIGNED, SEE T123P2.O
F114AO.O	SPECIAL STUDY
F115AO.O	GASTRIC CARCINOMA
F116AO.O	REASSIGNED, SEE F5O1P2.O+
F117AO.O	REASSIGNED, SEE F5O1R4.O+
F118AO.O	REASSIGNED, SEE F5O1P1.O+
F119AO.O	REASSIGNED, SEE F5O1P1.7+
F12OAO.O	REASSIGNED, SEE F5O1P3.O+
F121AO.O	REASSIGNED, SEE F5O1R3.O+
F122AO.O	REASSIGNED, SEE F5O2P3.O+
F123AO.O	ACCIDENTAL STRANGULATION
F124AO.O	REASSIGNED, SEE F5O2P1.7+
F125AO.O	REASSIGNED, SEE F5O2P2.O+
F126AO.O	REASSIGNED, SEE F5O3P1.7
F127AO.O	REASSIGNED, SEE F5O3P2.O+
F128AO.O	REASSIGNED, SEE F5O2R4.O+
F129AO.O	REASSIGNED, SEE F5O3R3.O+
F13OAO.O	
F131AO.O	
F132AO.O	
F133AO.O	
F134AO.O	
F135AO.O	
M136AO.O	
F137AO.O	REASSIGNED; SEE F5O4R5.O+
F138AO.O	REASSIGNED; SEE F5O4P2.O+

P. ANICILLARY

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	AGE (DAYS) AS OF 31/3/79	DEATH	DOSE TO SKELETON (RADS)
F139AO.O							
F140AO.O							
F141AO.O						1830	
F142AO.O							
F143AO.O					2092		
F144AO.O					2264		
F145AO.O					2280		
F146AO.O					2058		
F147AO.O							
F148AO.O						1801	
F149AO.O					1906		
F150AO.O					1793		
F151AO.O					1793		
F152AO.O						568	
F153AO.O					1870		
F154AO.O					1732		
F155AO.O					1730		
F156AO.O					1745		
F157AO.O					1732		
F158AO.O					1721		
F159AO.O					1515		
F160AO.O							
F161AO.O					1515		
F162AO.O					1515		
F163AO.O						1257	
F164AO.O							
M165AO.O					730		
M166AO.O						388	
M167AO.O						369	
M168AO.O						517	
M169AO.O						513	
M170AO.O						510	
M171AO.O						95	
F172AO.O						518	
F173AO.O						89	
F174AO.O						94	
F175AO.O						520	
F176AO.O						521	
M177AO.O						3420	
M178AO.O						1168	
M179AO.O						4125	
F180AO.O						3658	
M181AO.O						1211	

P. ANCILLARY

DOG NUMBER	COMMENTS ON DEAD DOGS
F139AO.O	REASSIGNED; SEE F5O5P2.O+
F14OAO.O	REASSIGNED; SEE F5O5P1.7+
F141AO.O	CHRONIC PANCREATITIS
F142AO.O	REASSIGNED; SEE F5O3P1.O+
F143AO.O	
F144AO.O	
F145AO.O	
F146AO.O	
F147AO.O	REASSIGNED; SEE F5O6P1.7+
F148AO.O	SPECIAL STUDY
F149AO.O	
F15OAO.O	
F151AO.O	
F152AO.O	SPECIAL STUDY
F153AO.O	
F154AO.O	
F155AO.O	
F156AO.O	
F157AO.O	
F158AO.O	
F159AO.O	
F16OAO.O	REASSIGNED; SEE T211P2.O
F161AO.O	
F162AO.O	
F163AO.O	SPECIAL STUDY
F164AO.O	REASSIGNED; SEE T2O6P2.O
M165AO.O	SPECIAL STUDY
M166AO.O	SPECIAL STUDY
M167AO.O	SPECIAL STUDY
M168AO.O	SPECIAL STUDY
M169AO.O	SPECIAL STUDY
M17OAO.O	SPECIAL STUDY
M171AO.O	SPECIAL STUDY
F172AO.O	SPECIAL STUDY
F173AO.O	SPECIAL STUDY
F174AO.O	SPECIAL STUDY
F175AO.O	SPECIAL STUDY
F176AO.O	SPECIAL STUDY
M177AO.O	SPECIAL STUDY
M178AO.O	SPECIAL STUDY
M179AO.O	SPECIAL STUDY
F18OAO.O	SPECIAL STUDY
M181AO.O	SPECIAL STUDY

P. ANICILLARY

DOG NUMBER	INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (uCi/KG)	DATE INJECTED D MO YR	AGE (DAYS) AS OF 31/3/79	DEATH	DOSE TO SKELETON (RADS)
M182AO.O						196	
M183AO.O						3064	
F184AO.O						184	
M185AO.O						524	
M186AO.O						189	
F187AO.O						93	
F188AO.O						193	
F189AO.O						262	
F190AO.O						372	
F191AO.O						176	
M192AO.O						91	
M193AO.O						369	
F194AO.O						371	
M195AO.O						362	
M196AO.O						1168	
M197AO.O						275	
F198AO.O						274	
M199AO.O						279	
M200AO.O						263	
F201AO.O						267	
M202AO.O						4150	
F203AO.O						3546	
M204AO.O						182	
F205AO.O						91	
F206AO.O					1347		
F207AO.O					1316		
M208AO.O						797	
M209AO.O						782	
M210AO.O					1389		
F211AO.O					1217		
F212AO.O							
F213AO.O							
F214AO.O							
F215AO.O					1116		
F216AO.O					1915		
F217AO.O					1515		
F218AO.O					1497		
F219AO.O					1473		
F220AO.O					1425		
F221AO.O							
F222AO.O					934		
F223AO.O					558		
F224AO.O					548		

P. ANCILLARY

DOG NUMBER	COMMENTS ON DEAD DOGS
M182AO.O	SPECIAL STUDY
M183AO.O	SPECIAL STUDY
F184AO.O	SPECIAL STUDY
M185AO.O	SPECIAL STUDY
M186AO.O	SPECIAL STUDY
F187AO.O	SPECIAL STUDY
F188AO.O	SPECIAL STUDY
F189AO.O	SPECIAL STUDY
F190AO.O	SPECIAL STUDY
F191AO.O	SPECIAL STUDY
M192AO.O	SPECIAL STUDY
M193AO.O	SPECIAL STUDY
F194AO.O	SPECIAL STUDY
M195AO.O	SPECIAL STUDY
M196AO.O	SPECIAL STUDY
M197AO.O	SPECIAL STUDY
F198AO.O	SPECIAL STUDY
M199AO.O	SPECIAL STUDY
M200AO.O	SPECIAL STUDY
F201AO.O	SPECIAL STUDY
M202AO.O	SPECIAL STUDY
F203AO.O	SPECIAL STUDY
M204AO.O	SPECIAL STUDY
F205AO.O	SPECIAL STUDY
F206AO.O	
F207AO.O	
M208AO.O	SPECIAL STUDY
M209AO.O	SPECIAL STUDY
M210AO.O	
F211AO.O	
F212AO.O	REASSIGNED; SEE T207P2.O
F213AO.O	REASSIGNED; SEE T208P2.O
F214AO.O	REASSIGNED; SEE T209P2.O
F215AO.O	
F216AO.O	
F217AO.O	
F218AO.O	
F219AO.O	
F220AO.O	
F221AO.O	REASSIGNED; SEE T212P2.O
F222AO.O	
F223AO.O	
F224AO.O	