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Research in Radiobiology

**Semi-Annual Report of Progress
in the Internal Irradiation Program**

of the

**RADIOBIOLOGY DIVISION OF THE DEPARTMENT OF ANATOMY
UNIVERSITY OF UTAH COLLEGE OF MEDICINE**

Respectfully Submitted by

THOMAS F. DOUGHERTY, Director

SEPTEMBER 30, 1965

RELEASED FOR ANNOUNCEMENT

IN NUCLEAR SCIENCE ABSTRACTS

CONTRACT NO. AT (11-1)-119

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RESEARCH IN RADIOBIOLOGY

Semi-Annual Report of Work in Progress in the Internal Irradiation Program

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Radiobiology Division of the Department of Anatomy,
University of Utah College of Medicine

Respectfully Submitted by:

Thomas F. Dougherty, Director

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Contract No. AT(11-1)-119

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AVAILABILITY OF PREVIOUS REPORTS

Copies of our reports may be obtained from the Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.

<u>Report</u>	<u>Date</u>	<u>Title</u>	<u>Photocopy</u>	<u>Microfilm</u>
C00-119-233 *	Sep 1965	Research in Radiobiology	\$10.90	\$ 5.45
C00-119-232 *	Mar 1965	Research in Radiobiology	22.20	11.10
C00-119-231 *	Sep 1964	Research in Radiobiology	17.20	8.60
C00-119-230 *	Jul 1964	Safety Manual	3.10	1.55
C00-119-229 *	Mar 1964	Research in Radiobiology	13.00	5.84
C00-228 *	Sep 1963	Research in Radiobiology	13.00	5.84
C00-227 *	Mar 1963	Research in Radiobiology	15.50	7.22
C00-226 *	Sep 1962	Research in Radiobiology	10.50	4.31
C00-225	Mar 1962	Research in Radiobiology	10.50	4.28
C00-224 *	Sep 1961	Research in Radiobiology	9.10	3.32
C00-223 *	Mar 1961	Research in Radiobiology	6.30	3.00
C00-222 *	Sep 1960	Research in Radiobiology	22.80	7.20
C00-221 *	Aug 1960	Interim Report of Sr ⁹⁰	3.30	2.40
C00-220 *	Mar 1960	Research in Radiobiology	34.80	9.90
C00-219 *	Sep 1959	Semi-Annual Report	10.80	3.90
C00-218 *	Mar 1959	Annual Report	34.80	9.90
AECU-4112	Feb 1959	Radioactive Fallout	3.30	2.40
C00-217 *	Sep 1958	Semi-Annual Report	28.80	8.40
C00-216 *	Mar 1958	Escape of Radon & Thoron	9.30	6.30
C00-215 *	Mar 1958	Annual Report	28.80	8.40
AECU-3583	Sep 1957	Semi-Annual Report	19.80	6.30
AECU-3522	Mar 1957	Annual Report	27.30	8.10
TID-16459	Sep 1956	Semi-Annual Report	5.60	2.05
TID-16458	Mar 1956	Annual Report	10.50	4.40
AECU-3109	Sep 1955	Semi-Annual Report	12.30	4.50
AECU-3418	Mar 1955	Annual Report	9.30	3.60
TID-7639	Consultants Meeting		19.75	9.40

*

Also available on request from this laboratory.

GROUP LEADERS AND SECTIONS

Division of Radiobiology, Department of Anatomy,
University of Utah College of Medicine

Section	Group Leader
Director	Prof. Thomas F. Dougherty
Biochemistry	Dr. David L. Berliner
Bone	Dr. Webster S. S. Jee
Chemistry	Dr. Betsy J. Stover
Clinic & Pathology	Dr. Glenn N. Taylor
Hematology	Dr. Jean H. Dougherty
Physics	Dr. Charles W. Mays
Radiology	Dr. William R. Christensen

CURRENT CENSUS OF THE BEAGLE COLONY

September 30, 1965

Assignment	Number of Dogs
Plutonium, toxicity (Pu-239)	50
Plutonium, test (Pu-239)	2
Radium, toxicity (Ra-226)	46
Radium, test (Ra-226)	3
Quickradium, test (Ra-224)	10
Radiothorium, toxicity (Th-228)	49
Radiothorium, test (Th-228)	0
Mesothorium, toxicity (Ra-228)	48
Mesothorium, test (Ra-228)	0
Strontium, toxicity (Sr-90)	64
Strontium, test (Sr-90)	1
Controls, aging	45
Controls, x-ray	5
Unassigned (Male 68, Female 64)	132
	<hr/> 455

INJECTION TABLES

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

Dogs are put into the toxicity study groups of six or seven of the same sex (five or six dose levels plus one control). Litter mates are used whenever possible. Each animal receives the designated dose of one radionuclide in a single I.V. injection. The animals are injected at approximately 17 months of age. At this age the skeleton is mature with all epiphyses fused except those of the ribs. Twelve such groups have been injected for each of the five radionuclides, Ra^{226} , Pu^{239} , Ra^{228} , Th^{228} , and Sr^{90} . The current injection program is limited to Ra^{226} and Pu^{239} at lower dose levels.

The five dose levels designated by integers are those specified at the early meetings of the consultants, and those designated by non-integers have been added by the laboratory staff. Since those dose levels were originally specified as "retained" doses, the actual injected doses are four times the desired "retained" doses of Ra^{226} , Ra^{228} (Mesothorium), and Sr^{90} , and 1.11 times the desired "retained" doses of Pu^{239} and Th^{228} (Radiothorium). * The desired "retained" activities are the same for all

* Since radioactive decay and excretion occur continuously, the term "retained" dose is obviously meaningless unless the time after injection is specified. Our present measurements indicate that

average Ra^{226}	retention = 0.25 after 271 days
average Pu^{239}	retention = 0.90 after 6 days
average Ra^{228}	retention = 0.25 after 214 days
average Th^{228}	retention = 0.90 after 6 days
average Sr^{90}	retention = 0.25 after 135 days

the radionuclides except Sr^{90} , in which case they are greater by a factor of 10. Dose level 1 is the basis of the scheme, and is 10 times the maximum permissible Ra^{226} in man. $\text{Level 1} = 10 \times \frac{0.1 \mu\text{C Ra}^{226}}{70 \text{ kg man}} = 0.0143$ "retained" $\mu\text{C/kg}$. All other dose 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 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 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 = Ra^{226} , P = Pu^{239} , M = Ra^{228} , T = Th^{228} , S = Sr^{90} , Q = Ra^{224} , J = Sr^{85} , and A = Aging Control.

"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 assignment to serial sacrifice schedule. Any of the above letters denoting a radionuclide may follow the final number, in which case the letter indicates that two radionuclides were given. The dose 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 dose 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 dose 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 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; these tumors were the subject of a separate report, Research in Radiobiology, September 30, 1963 (C00-228), pp. 95-108. 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 eminent or when life could no longer be humanely prolonged.

DOSIMETRY REVISIONS

A number of new values appear for the dose in rads to the skeleton at death. Ra^{226} , Ra^{228} , and Sr^{90} doses are calculated for each dog using his individually observed retention values: Pu^{239} and Th^{228} doses are from our average skeletal retention equations.

For our standard beagle, the following equations were used for the effective* skeletal retention at (t) days after injection:

$$\text{Ra}^{226} = 0.412e^{-0.558t} + 0.105e^{-0.0730t} + 0.196e^{-0.00488t} + 0.287e^{-0.000299t}$$

(5-level only)

$$\text{Ra}^{226} = 0.251e^{-0.982t} + 0.211e^{-0.269t} + 0.210e^{-0.0155t} + 0.177e^{-0.00204t} + 0.151e^{-0.000150t}$$

(lower levels)

$$\text{Rn}^{222}/\text{Ra}^{226} = 0.075 \left[1 - e^{-0.181t} \right] t^{0.158}$$

(all levels)

$$\text{Pu}^{239} = 0.72 t^{-0.040}$$

$$\text{Ra}^{228} = 0.251e^{-0.982t} + 0.211e^{-0.269t} + 0.210e^{-0.0158t} + 0.177e^{-0.00237t} + 0.151e^{-0.000479t}$$

(pure at t = 0)

84.4% retention of in vivo produced Th^{228} and daughters.

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

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

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

$$\text{Sr}^{90} = 0.402e^{-0.748t} + 0.259e^{-0.102t} + 0.181e^{-0.00469t} + 0.158e^{-0.000302t}$$

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

We hope to present our detailed retention data and dosimetric analysis in a future report.

Ra^{228} doses deserve special comment. The dose from "pure" Ra^{228} and its in vivo produced daughters is based on our best evaluation of 5.77 ± 0.02 yr for the Ra^{228} half-period. The tabulated total doses include the contributions from Th^{228} contamination in the injection solutions. For example, Th^{228} contaminations of 0.6%, 3%, and 15%, respectively, account for 2.8%, 13% and 42% of the total dose in rads at 1000 days. If injected Th^{228} is 4 times more toxic rad-for-rad than is in vivo produced Th^{228} , these injected Th^{228} 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% Th^{228}) dogs in evaluation of Ra^{228} toxicity.

TABLE I. TOXICITY ANIMALS (SEPT. 30, 1965)

A. RADIUM-226

DOG NUMBER	AT INJECTION		INJECTED ($\mu\text{C/KG}$)	DATE INJECTED			DAYS SINCE INJECTION		DOSE TO SKELETON (RADS)
	AGE (DAYS)	WEIGHT (KG)		D	MO	YR	30/9/65	DEATH	
M01R0.0	558	8.03		20	04	53		3116	
M02R0.0	487	14.6		16	11	53		3675	
F03R0.0	601	11.4		10	03	54		2139	
M04R0.0	461	11.0		7	04	54	4194		
M05R0.0	460	6.57		22	06	54		4018	
F06R0.0	483	8.43		27	7	54		3182	
M07R0.0	511	11.0		24	8	54		3360	
F08R0.0	638	8.21		21	12	54		3361	
F09R0.0	700	11.7		11	4	55		1550	
M10R0.0	522	10.9		27	07	55	3718		
F11R0.0	544	10.2		20	12	55	3572		
F12R0.0	501	8.68		17	01	56	3544		
M13R0.0	515	12.3		4	3	54	575		
F14R0.0	536	10.8		23	10	54	342		
M15R0.0	564	12.8		4	2	55	238		
F16R0.0	469	10.0		7	4	55	176		
F31R0.0B	536	10.6		23	10	54	342		
F31R0.0C	536	9.88		23	10	54	342		
F31R0.0D	542	9.9		21	9	55	9		
F32R0.0B	542	7.8		21	9	55	9		
F32R0.0C	532	11.7		21	9	55	9		
F32R0.0D	532	9.7		21	9	55	9		
F33R0.0B	532	9.8		21	9	55	9		
M13R0.2	529	9.77	.00577	4	3	54	575		
F14R0.2	460	8.10	.00836	23	10	54	342		
M15R0.2	504	10.8	.00873	4	2	55	238		
F16R0.2	485	8.90	.00665	7	4	55	176		
M13R0.5	529	11.0	.0171	4	3	54	575		
F14R0.5	510	9.75	.0220	23	10	54	342		
M15R0.5	490	10.4	.0263	4	2	55	238		
F16R0.5	500	11.4	.0205	7	4	55	176		
M01R1.0	471	8.48	.0618	20	04	53	4546		
M02R1.0	627	10.0	.0876	16	11	53		4054	237
F03R1.0	706	8.68	.0576	10	03	54		3850	151

DOG
NUMBER

COMMENTS ON DEAD DOGS

M01R0.0 SEMINOMA, LYMPHOSARCOMA
M02R0.0 TRANSITIONAL CELL CARCINOMA
F03R0.0 STATUS EPILEPTICUS
M04R0.0
M05R0.0 OBTURATING PULMONARY EMBOLISM
F06R0.0 STATUS EPILEPTICUS
M07R0.0 STATUS EPILEPTICUS, NEPHRITIS
F08R0.0 PANCREATIC ADENOCARCINOMA
F09R0.0 AORTIC BODY TUMOR
M10R0.0
F11R0.0
F12R0.0
M13R0.0
F14R0.0
M15R0.0
F16R0.0
F31R0.0B
F31R0.0C
F31R0.0D
F32R0.0B
F32R0.0C
F32R0.0D
F33R0.0B

M13R0.2
F14R0.2
M15R0.2
F16R0.2

M13R0.5
F14R0.5
M15R0.5
F16R0.5

M01R1.0
M02R1.0 SEMINOMA
F03R1.0 MAMMARY GLAND CARCINOMA

DOG NUMBER	AT INJECTION		INJECTED (μ C/KG)	DATE INJECTED			DAYS SINCE INJECTION		DOSE TO SKELETON (RADS)
	AGE (DAYS)	WEIGHT (KG)		D	MO	YR	30/9/65	DEATH	
M04R1.0	414	8.60	.0642	7	04	54		2038	108
M05R1.0	490	11.7	.0436	22	06	54		3780	112
F06R1.0	483	7.23	.0584	27	07	54	4083		
M07R1.0	511	11.4	.0651	24	8	54		3544	167
F08R1.0	861	8.98	.0559	21	12	54		2988	93
F09R1.0	781	9.88	.0521	11	04	55	3825		
M10R1.0	523	11.5	.0573	27	07	55	3718		
F11R1.0	511	11.2	.0522	20	12	55	3572		
F12R1.0	501	9.71	.0444	17	01	56	3544		
M13R1.0	529	11.7	.0527	4	3	64	575		
F14R1.0	510	10.5	.0701	23	10	64	342		
M15R1.0	490	8.88	.0797	4	2	55	238		
F16R1.0	501	8.99	.0611	7	4	55	176		
M01R1.7	523	9.98	.137	17	01	56	3544		
M02R1.7	598	7.85	.163	30	11	56		1273	116
M02R1.7A	493	12.0	.222	6	3	63	939		
F03R1.7	473	13.1	.165	20	12	55		3267	385
M04R1.7	514	6.20	.163	20	12	55	3572		
M05R1.7	511	10.1	.151	20	12	55	3572		
F06R1.7	491	7.9	.152	20	12	55		3432	417
M07R1.7	598	7.17	.163	30	11	56		3142	309
F08R1.7	491	9.50	.154	20	12	55		2577	378
F09R1.7	598	7.55	.168	30	11	56	3226		
M10R1.7	590	9.57	.167	30	11	56		557	109
M10R1.7A	545	10.6	.183	7	01	59	2458		
F11R1.7	598	8.17	.165	30	11	56	3226		
F12R1.7	590	8.95	.167	30	11	56		2399	210
M01R2.0	471	8.74	.382	20	04	53		3440	860
M02R2.0	592	8.21	.387	16	11	53		3775	625
F03R2.0	541	8.53	.347	10	03	54	4222		
M04R2.0	414	10.5	.361	7	04	54		325	189
M04R2.0A	420	10.6	.306	11	04	55	3825		
M05R2.0	461	11.5	.267	22	06	54	4118		
F06R2.0	486	10.6	.360	27	07	54	4083		
M07R2.0	514	11.1	.413	24	8	54		3425	922
F08R2.0	572	6.95	.331	21	12	54	3936		
F09R2.0	592	9.38	.317	11	04	55	3825		

DOG
NUMBER

COMMENTS ON DEAD DOGS

M04R1.0	TRAUMA
M05R1.0	TRANSITIONAL CELL CARCINOMA, HYDRONEPHROSIS
F06R1.0	
M07R1.0	STATUS EPILEPTICUS
F08R1.0	LYMPHOSARCOMA
F09R1.0	
M10R1.0	
F11R1.0	
F12R1.0	
M13R1.0	
F14R1.0	
M15R1.0	
F16R1.0	
M01R1.7	
M02R1.7	LYMPHOSARCOMA
M02R1.7A	
F03R1.7	MAMMARY GLAND CARCINOMA
M04R1.7	
M05R1.7	
F06R1.7	
M07R1.7	BACTERIAL TOXEMIA INTERSTITIAL CELL CARCINOMA
F08R1.7	DRUG ALLERGY
F09R1.7	
M10R1.7	TRAUMA
M10R1.7A	
F11R1.7	
F12R1.7	NOT DETERMINED
M01R2.0	HEMANGIOSARCOMA
M02R2.0	OSTEOSARCOMA
F03R2.0	
M04R2.0	PERFORATED ILEUM
M04R2.0A	
M05R2.0	
F06R2.0	
M07R2.0	OSTEOSARCOMA, CUSHING SYNDROME
F08R2.0	
F09R2.0	

DOG NUMBER	AT INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (μ C/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 30/9/65 DEATH	DOSE TO SKELETON (RADS)
M10R2.0	523	9.95	.345	27 07 55	3569	1220
F11R2.0	495	9.30	.310	20 12 55	3297	728
F12R2.0	497	10.3	.281	17 1 56	2948	742
M01R3.0	473	8.91	1.20	20 04 53	2850	2395
M02R3.0	470	9.02	1.21	16 11 53	2226	1727
F03R3.0	386	7.74	1.11	10 03 54	2497	2323
M04R3.0	412	11.7	1.16	7 04 54	1917	2361
M05R3.0	461	13.0	.846	22 06 54	2955	2317
F06R3.0	486	9.75	1.14	27 07 54	1932	2246
M07R3.0	514	12.3	1.29	24 08 54	2099	3029
F08R3.0	542	7.76	1.03	21 12 54	2612	1916
F09R3.0	551	8.02	.987	11 04 55	2487	1839
M10R3.0	525	10.1	1.06	27 07 55	1737	2336
F11R3.0	495	12.9	.938	20 12 55	1610	1333
F12R3.0	497	11.4	.883	17 1 56	1897	1639
M01R4.0	471	9.08	3.51	20 04 53	1606	6575
M02R4.0	470	9.53	3.55	16 11 53	1884	6150
F03R4.0	384	8.65	3.33	10 03 54	490	2208
FQ3R4.0A	598	7.20	3.10	30 11 56	1614	3855
M04R4.0	408	8.83	3.47	7 04 54	1518	6063
M05R4.0	461	13.2	2.42	22 06 54	1659	4505
F06R4.0	486	8.55	3.44	27 07 54	1939	7133
M07R4.0	453	9.55	3.88	24 8 54	1647	5844
F08R4.0	474	8.94	3.14	21 12 54	1324	4615
F09R4.0	542	8.53	3.02	11 04 55	1471	4095
M10R4.0	527	10.8	3.28	27 07 55	1553	7582
F11R4.0	491	10.4	2.84	20 12 55	1469	5273
F12R4.0	496	9.61	2.81	17 01 56	1435	3877
M01R5.0	473	9.87	10.5	20 04 53	908	14943
M02R5.0	470	8.85	10.8	16 11 53	1380	18071
F03R5.0	380	7.82	10.1	10 03 54	481	7147
M04R5.0	408	8.90	10.6	7 04 54	1091	16417
M05R5.0	458	10.9	10.1	22 6 54	1220	15433
F06R5.0	486	9.66	10.2	27 07 54	1015	15414

DOG
NUMBER

COMMENTS ON DEAD DOGS

M10R2.0 OSTEOSARCOMA
F11R2.0 OSTEOSARCOMA
F12R2.0 MAMMARY ADENOCARCINOMA

M01R3.0 OSTEOSARCOMA
M02R3.0 OSTEOSARCOMA
F03R3.0 OSTEOSARCOMA
M04R3.0 OSTEOSARCOMA
M05R3.0 OSTEOSARCOMA
F06R3.0 OSTEOSARCOMA
M07R3.0 OSTEOSARCOMA
F08R3.0 OSTEOSARCOMA
F09R3.0 OSTEOSARCOMA
M10R3.0 OSTEOSARCOMA
F11R3.0 PYOMETRITIS + SECONDARY PERITONITIS
F12R3.0 OSTEOSARCOMA

M01R4.0 OSTEOSARCOMA
M02R4.0 OSTEOSARCOMA
F03R4.0 CANINE DISTEMPER
F03R4.0A OSTEOSARCOMA
M04R4.0 OSTEOSARCOMA
M05R4.0 OSTEOSARCOMA
F06R4.0 OSTEOSARCOMA
M07R4.0 OSTEOSARCOMA
F08R4.0 OSTEOSARCOMA
F09R4.0 OSTEOSARCOMA
M10R4.0 OSTEOSARCOMA
F11R4.0 OSTEOSARCOMA
F12R4.0 OSTEOSARCOMA

M01R5.0 OSTEOSARCOMA
M02R5.0 OSTEOSARCOMA
F03R5.0 CANINE DISTEMPER
M04R5.0 OSTEOSARCOMA
M05R5.0 OSTEOSARCOMA
F06R5.0 OSTEOSARCOMA

DOG NUMBER	AT INJECTION		INJECTED (μ C/KG)	DATE INJECTED			DAYS SINCE INJECTION 30/9/65 DEATH	DOSE TO SKELETON (RADS)
	AGE (DAYS)	WEIGHT (KG)		D	MO	YR		
M07R5.0	453	8.85	11.9	24	08	54	1288	16708
F08R5.0	474	7.76	9.68	21	12	54	968	11564
F09R5.0	420	9.16	9.48	11	04	55	1288	15941
M10R5.0	527	10.7	10.2	27	07	55	825	11179

DOG

NUMBER :

COMMENTS ON DEAD DOGS

M07R5.0 OSTEOSARCOMA
F08R5.0 OSTEOSARCOMA
F09R5.0 OSTEOSARCOMA + ANEMIA
M10R5.0 OSTEOSARCOMA + FRACTURED MANDIBLE

B. PLUTONIUM-239

DOG NUMBER	AT INJECTION		INJECTED (μ C/KG)	DATE INJECTED			DAYS SINCE INJECTION 30/9/65 DEATH	DOSE TO SKELETON (RADS)
	AGE (DAYS)	WEIGHT (KG)		D	MO	YR		
M01P0.0	443	9.70		1	12	52	4003	
F02P0.0	424	6.36		2	03	53	2755	
M03P0.0	515	10.8		1	06	53	4504	
M04P0.0	426	10.7		15	09	53	4397	
F05P0.0	620	9.75		14	10	53	4088	
F06P0.0	410	5.59		12	05	54	4159	
F07P0.0	515	6.90		25	10	54	3993	
M08P0.0	585	10.9		15	03	55	3852	
F09P0.0	658	11.0		22	11	55	3032	
F10P0.0	658	11.0		22	11	55	3600	
M11P0.0	602	10.3		24	04	56	3446	
M12P0.0	630	10.9		29	05	56	3411	
F13P0.0	517	9.47		4	3	54	575	
F14P0.0	452	9.89		12	5	54	506	
M15P0.0	527	12.1		23	10	54	342	
M16P0.0	485	13.9		7	4	55	176	
M31P0.0B	452	11.8		12	5	54	506	
M31P0.0C	452	12.6		12	5	54	506	
M32P0.0B	452	11.2		12	5	54	506	
M32P0.0C	542	10.3		21	9	55	9	
M33P0.0B	517	12.1		21	9	55	9	
F13P0.1	515	9.46	.00068	4	3	54	575	
F14P0.1	452	10.3	.00055	12	5	54	506	
M15P0.1	536	9.67	.00071	23	10	54	342	
M16P0.1	501	12.0	.00059	7	4	55	176	
M31P0.1B	517	12.2	.00068	4	3	54	575	
F13P0.2	517	9.44	.00206	4	3	54	575	
F14P0.2	516	7.44	.00173	12	5	54	506	
M15P0.2	505	10.9	.00201	23	10	54	342	
M16P0.2	500	11.4	.00163	7	4	55	176	
M31P0.2B	515	10.7	.00185	4	3	54	575	
F31P0.2C	452	11.9	.00169	12	5	54	506	
F31P0.2D	429	9.35	.00186	12	5	54	506	
F32P0.2C	494	10.1	.00183	4	2	55	238	
F32P0.2D	490	8.04	.00193	4	2	55	238	
F13P0.5	517	9.93	.00540	4	3	54	575	

DOG
NUMBER

COMMENTS ON DEAD DOGS

M01P0.0 SPLENIC RUPTURE, METASTATIC SEMINOMA

F02P0.0 ANESTHETIC ACCIDENT

M03P0.0

M04P0.0

F05P0.0 ADRENAL CORTICAL CARCINOMA

F06P0.0

F07P0.0

M08P0.0

F09P0.0 PULMONARY EMBOLISM, NEPHRITIS

F10P0.0

M11P0.0

M12P0.0

F13P0.0

F14P0.0

M15P0.0

M16P0.0

M31P0.0B

M31P0.0C

M32P0.0B

M32P0.0C

M33P0.0B

F13P0.1

F14P0.1

M15P0.1

M16P0.1

M31P0.1B

F13P0.2

F14P0.2

M15P0.2

M16P0.2

M31P0.2B

F31P0.2C

F31P0.2D

F32P0.2C

F32P0.2D

F13P0.5

DOG NUMBER	AT INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (μ C/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 30/9/65	DEATH	DOSE TO SKELETON (RADS)
F14P0.5	516	9.98	.00493	12 5 64	506		
M15P0.5	505	8.41	.00627	23 10 64	342		
M16P0.5	501	12.6	.00521	7 4 65	176		
M31P0.5B	515	10.5	.00549	4 3 64	575		
F32P0.5C	494	8.44	.00571	4 2 65	238		
M01P1.0	442	9.41	.0150	1 12 52	4572		98
F02P1.0	422	6.85	.0163	2 03 53	4595		
M03P1.0	515	8.00	.0165	1 06 53	4292		102
M04P1.0	608	9.97	.0139	16 09 53	4397		
F05P1.0	620	8.80	.0142	14 10 53	1539		30
F05P1.0A	472	11.0	.0168	3 09 58	2584		
F06P1.0	410	7.38	.0140	12 05 54	4159		
F07P1.0	510	6.36	.0167	25 10 54	3981		96
M08P1.0	453	10.6	.0172	15 3 55	3367		83
F09P1.0	556	7.87	.0168	9 09 55	2257		60
F10P1.0	641	12.00	.0152	22 11 55	3600		
M11P1.0	602	8.90	.0157	24 04 56	3446		
M12P1.0	629	9.67	.0167	29 5 56	2374		60
M13P1.0	504	12.7	.0153	3 09 58	2584		
M01P1.7	657	8.72	.0475	26 06 56	3025		210
F02P1.7	527	8.62	.0431	22 11 55	3430		215
M03P1.7	642	8.63	.0495	26 06 56	3383		
M04P1.7	673	8.37	.0484	10 10 56	3277		
F05P1.7	642	11.6	.0493	26 6 56	2659		190
F06P1.7	642	10.3	.0459	26 06 56	2221		170
F07P1.7	756	9.73	.0481	10 10 56	3277		
M08P1.7	673	13.6	.0479	10 10 56	3277		
F09P1.7	756	9.72	.0485	10 10 56	2500		180
F10P1.7	739	10.6	.0495	10 10 56	467		40
F10P1.7A	472	8.07	.0457	3 09 58	2584		
M11P1.7	599	11.6	.0486	24 4 56	2777		200
M12P1.7	673	9.41	.0491	10 10 56	2973		213
M13P1.7	504	10.60	.0473	3 09 58	2584		
M01P2.0	442	7.61	.0853	1 12 52	2985		370

DOG
NUMBER

COMMENTS ON DEAD DOGS

F14P0.5
M15P0.5
M16P0.5
M31P0.5B
F32P0.5C

M01P1.0 OSTEOSARCOMA
F02P1.0
M03P1.0 OSTEOSARCOMA
M04P1.0
F05P1.0 COLITIS, ENTERITIS + SECONDARY HEPATIC NECROSIS
F05P1.0A
F06P1.0
F07P1.0 TRAUMA LYMPHADENOPHATHY
M08P1.0 OSTEOSARCOMA
F09P1.0 OSTEOSARCOMA
F10P1.0
M11P1.0
M12P1.0 CHRONIC PANCREATITIS
M13P1.0

M01P1.7 OSTEOSARCOMA
F02P1.7 OSTEOSARCOMA
M03P1.7
M04P1.7
F05P1.7 OSTEOSARCOMA
F06P1.7 OSTEOSARCOMA
F07P1.7
M08P1.7
F09P1.7 OSTEOSARCOMA
F10P1.7 ACUTE ENTERITIS
F10P1.7A
M11P1.7 BILE DUCT CARCINOMA
M12P1.7 LEUKEMIA
M13P1.7

M01P2.0 OSTEOSARCOMA

DOG NUMBER	AT INJECTION		INJECTED ($\mu\text{C/KG}$)	DATE INJECTED			DAYS SINCE INJECTION		DOSE TO SKELETON (RADS)
	AGE (DAYS)	WEIGHT (KG)		D	MO	YR	30/9/65	DEATH	
F02P2.0	422	7.73	.112	2	03	53		2780	460
M03P2.0	485	10.5	.0940	1	06	53		3185	420
M04P2.0	608	9.84	.0862	16	09	53		2948	380
F05P2.0	594	8.12	.0846	14	10	53		2423	310
F06P2.0	417	7.54	.0902	12	05	54		2947	370
F07P2.0	485	8.40	.0996	25	10	54		2093	310
M08P2.0	406	9.73	.0957	15	03	55		1761	250
F09P2.0	552	9.72	.101	9	09	55		2014	300
F10P2.0	551	7.94	.0968	22	11	55		2912	410
M11P2.0	599	10.3	.0961	24	04	56		1617	230
M12P2.0	622	9.98	.100	29	05	56		2284	370
M01P3.0	417	8.00	.261	1	12	52		1476	580
F02P3.0	422	6.85	.312	2	03	53		1947	900
M03P3.0	485	8.74	.291	1	06	53		1604	700
M04P3.0	608	8.51	.292	16	09	53		1950	840
F05P3.0	650	8.22	.288	14	10	53		1504	630
F06P3.0	415	8.38	.282	12	05	54		1617	670
F07P3.0	485	9.00	.314	25	10	54		1627	750
M08P3.0	406	9.73	.300	15	03	55		1771	780
F09P3.0	552	7.67	.300	9	09	55		1894	840
F10P3.0	533	8.94	.298	22	11	55		1547	700
M11P3.0	599	10.5	.309	24	04	56		1198	550
M12P3.0	622	10.2	.308	29	05	56		1659	760
M01P4.0	442	7.61	.823	1	12	52		1724	2100
F02P4.0	567	8.65	1.03	2	03	53		1556	2380
M03P4.0	485	9.36	.929	1	06	53		1198	1680
M04P4.0	566	8.74	.974	16	09	53		1066	1560
F05P4.0	650	7.05	.872	14	10	53		1245	1650
F06P4.0	420	9.26	.811	12	05	54		1357	1660
F07P4.0	485	8.45	.963	25	10	54		1198	1730
M08P4.0	651	9.22	.887	15	03	55		1157	1560
F09P4.0	552	8.58	.960	9	09	55		1343	1920
F10P4.0	527	6.48	.868	22	11	55		1241	1660
M11P4.0	596	9.56	.927	24	04	56		1288	1790
M12P4.0	598	11.4	.838	29	05	56		1463	1840
M01P5.0	417	8.86	2.67	1	12	52		1324	5370

DOG
NUMBER

COMMENTS ON DEAD DOGS

F02P2.0 OSTEOSARCOMA
M03P2.0 OSTEOSARCOMA
M04P2.0 OSTEOSARCOMA
F05P2.0 OSTEOSARCOMA
F06P2.0 OSTEOSARCOMA
F07P2.0 SQUAMOUS CELL CARCINOMA
M08P2.0 ASPIRATION PNEUMONIA
F09P2.0 OSTEOSARCOMA
F10P2.0 OSTEOSARCOMA
M11P2.0 OSTEOSARCOMA
M12P2.0 OSTEOSARCOMA

M01P3.0 OSTEOSARCOMA
F02P3.0 OSTEOSARCOMA
M03P3.0 OSTEOSARCOMA
M04P3.0 OSTEOSARCOMA
F05P3.0 OSTEOSARCOMA
F06P3.0 OSTEOSARCOMA
F07P3.0 OSTEOSARCOMA
M08P3.0 OSTEOSARCOMA
F09P3.0 OSTEOSARCOMA
F10P3.0 OSTEOSARCOMA
M11P3.0 OSTEOSARCOMA
M12P3.0 OSTEOSARCOMA

M01P4.0 OSTEOSARCOMA
F02P4.0 OSTEOSARCOMA
M03P4.0 OSTEOSARCOMA
M04P4.0 OSTEOSARCOMA
F05P4.0 OSTEOSARCOMA
F06P4.0 OSTEOSARCOMA
F07P4.0 OSTEOSARCOMA
M08P4.0 OSTEOSARCOMA
F09P4.0 OSTEOSARCOMA
F10P4.0 OSTEOSARCOMA
M11P4.0 OSTEOSARCOMA
M12P4.0 OSTEOSARCOMA

M01P5.0 OSTEOSARCOMA

DOG NUMBER	AT INJECTION		INJECTED (μ C/KG)	DATE INJECTED			DAYS SINCE INJECTION 30/9/65 DEATH	DOSE TO SKELETON (RADS)
	AGE (DAYS)	WEIGHT (KG)		D	MO	YR		
F02P5.0	1150	8.75	3.30	2	03	53	1576	7830
M03P5.0	515	8.10	3.00	1	06	53	499	2340
M04P5.0	566	9.18	3.17	16	09	53	1562	7380
F05P5.0	691	8.77	2.77	14	10	53	2059	8690
F06P5.0	407	7.90	2.57	12	05	54	1194	4620
F07P5.0	482	8.33	2.99	25	10	54	1491	6630
M08P5.0	497	9.55	2.69	15	03	55	1192	4840
F09P5.0	552	9.45	2.73	9	09	55	1145	4750

DOG
NUMBER

COMMENTS ON DEAD DOGS

F02P5.0	OSTEOSARCOMA + FRACTURED MANDIBLE
M03P5.0	LIVER DEGENERATION + ASCITES
M04P5.0	OSTEOSARCOMA
F05P5.0	OSTEOSARCOMA, LIVER DEGENERATION + HEPATIC HEMORRHAGE
F06P5.0	OSTEOSARCOMA
F07P5.0	OSTEOSARCOMA + CRIPPLING FRACTURE
M08P5.0	GINGIVITIS
F09P5.0	OSTEOSARCOMA, EPISTAXIS + CIRCULATORY COLLAPSE

C. RADIUM-228 (MESOTHORIUM)*

DOG NUMBER	AT INJECTION		INJECTED (μ C/KG)	DATE INJECTED			DAYS SINCE INJECTION 30/9/65 DEATH	DOSE TO SKELETON (RADS)
	AGE (DAYS)	WEIGHT (KG)		D	MO	YR		
F01M0.0	732	7.33		4	1	54	3451	
F02M0.0	545	6.94		29	11	54	3958	
M03M0.0	579	13.0		13	03	56	3488	
M04M0.0	601	10.3		15	01	57	3180	
F05M0.0	671	11.2		5	03	57	3131	
M06M0.0	492	7.56		23	04	57	3082	
F07M0.0	395	8.71		4	6	57	1414	
F07M0.0A	594	10.9		15	1	63	989	
F08M0.0	654	11.6		9	03	60	2031	
M09M0.0	575	12.4		13	04	60	1996	
M10M0.0	581	13.3		17	7	62	1171	
F11M0.0	475	9.31		18	9	62	1108	
M12M0.0	695	10.0		22	12	60	1743	
F01M0.5	492	9.47	.0173	17	7	62	1171	
F02M0.5	492	9.15	.0173	17	7	62	1171	
M03M0.5	493	10.8	.0199	18	9	62	1108	
M04M0.5	475	12.8	.0199	18	9	62	1108	
F05M0.5	534	7.83	.0172	23	10	62	1073	
M06M0.5	510	10.3	.0171	23	10	62	1073	
F07M0.5	492	8.87	.0172	17	7	62	1171	
F08M0.5	654	12.6	.0159	9	03	60	2031	
M09M0.5	485	11.9	.0170	13	04	60	1996	
M10M0.5	492	10.6	.0174	17	7	62	1171	
F11M0.5	505	7.82	.0202	18	9	62	1108	
M12M0.5	510	10.6	.0165	23	10	62	1073	
F01M1.0	718	7.75	.0463	4	01	54	2952	196
F01M1.0A	590	8.07	.0512	23	10	62	1073	
F02M1.0	459	8.25	.0324	29	11	54	3958	
M03M1.0	575	13.8	.0589	13	03	56	3157	306
M04M1.0	601	9.90	.0481	15	01	57	3180	
F05M1.0	658	8.80	.0490	5	03	57	3131	
M06M1.0	521	10.6	.0468	23	04	57	3082	
F07M1.0	534	9.89	.0489	4	6	57	2159	149
F08M1.0	654	12.4	.0491	9	03	60	2031	
M09M1.0	485	10.1	.0504	13	04	60	1996	
M10M1.0	492	9.43	.0501	17	7	62	1171	
F11M1.0	505	8.91	.0613	18	9	62	1108	

DOG
NUMBER

COMMENTS ON DEAD DOGS

F01M0.0 PURULENT MENINGOENCEPHALITIS

F02M0.0

M03M0.0

M04M0.0

F05M0.0

M06M0.0

F07M0.0 STATUS EPILEPTICUS

F07M0.0A

F08M0.0

M09M0.0

M10M0.0

F11M0.0

M12M0.0

F01M0.5

F02M0.5

M03M0.5

M04M0.5

F05M0.5

M06M0.5

F07M0.5

F08M0.5

M09M0.5

M10M0.5

F11M0.5

M12M0.5

F01M1.0 HEMANGIOSARCOMA

F01M1.0A

F02M1.0

M03M1.0 OSTEOSARCOMA

M04M1.0

F05M1.0

M06M1.0

F07M1.0 HEMANGIOSARCOMA

F08M1.0

M09M1.0

M10M1.0

F11M1.0

DOG NUMBER	AT INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (μ c/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 30/9/65 DEATH	DOSE TO SKELETON (RADS)
M12M1.0	528	9.27	.0498	23 10 62	1073	
F01M1.7	510	7.52	.151	23 10 62	1073	
F02M1.7	560	9.90	.183	13 03 56	2383	733
M03M1.7	576	11.0	.180	13 3 56	2709	723
M04M1.7	601	8.94	.143	15 01 57	2864	424
F05M1.7	658	12.8	.141	5 03 57	3131	
M06M1.7	521	10.0	.144	23 04 57	3082	
F07M1.7	534	10.2	.146	4 6 57	2646	600
F08M1.7	654	10.8	.148	9 03 60	2031	
M09M1.7	485	12.6	.149	13 04 60	1996	
M10M1.7	492	10.1	.124	17 7 62	1171	
F11M1.7	505	10.7	.179	18 9 62	1108	
M12M1.7	524	9.28	.153	23 10 62	1073	
F01M2.0	676	7.60	.276	4 01 54	1780	870
F02M2.0	517	8.25	.194	29 11 54	965	198
M03M2.0	576	11.0	.358	13 03 56	619	355
M04M2.0	601	9.88	.282	15 1 57	2282	1033
F05M2.0	509	8.30	.295	5 3 57	2688	928
M06M2.0	502	12.4	.306	23 4 57	2674	1382
F07M2.0	534	10.1	.298	4 6 57	2239	1064
F08M2.0	654	12.4	.300	9 03 60	2031	
M09M2.0	630	9.99	.302	13 4 60	1254	561
M10M2.0	430	11.2	.311	17 7 62	1171	
F11M2.0	505	7.03	.381	18 9 62	1108	
M12M2.0	524	9.47	.306	23 10 62	1073	
F01M3.0	519	10.4	.858	4 01 54	918	1833
F02M3.0	460	6.70	.612	29 11 54	1856	2075
M03M3.0	579	10.4	.965	13 3 56	1185	2464
M04M3.0	601	10.2	.916	15 01 57	1176	1592
F05M3.0	531	8.51	.940	5 03 57	1869	2148
M06M3.0	502	9.09	.953	23 04 57	1421	1906
F07M3.0	534	9.94	.907	4 6 57	1463	3145
F08M3.0	633	11.8	.950	9 3 60	1447	2158
M09M3.0	630	9.83	.918	13 4 60	1570	2277

DOG NUMBER	COMMENTS ON DEAD DOGS
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M12M1.0

F01M1.7	
F02M1.7	OSTEOSARCOMA
M03M1.7	OSTEOSARCOMA
M04M1.7	CARCINOMA SMALL INTESTINE
F05M1.7	
M06M1.7	
F07M1.7	OSTEOSARCOMA
F08M1.7	
M09M1.7	
M10M1.7	
F11M1.7	
M12M1.7	

F01M2.0	OSTEOSARCOMA
F02M2.0	INTESTINAL HEMORRHAGE
M03M2.0	PNEUMONIA
M04M2.0	OSTEOSARCOMA
F05M2.0	OSTEOSARCOMA
M06M2.0	OSTEOSARCOMA
F07M2.0	CHRONIC PANCREATITIS
F08M2.0	
M09M2.0	RETICULUM CELL SARCOMA OF VERTEBRA
M10M2.0	
F11M2.0	
M12M2.0	

F01M3.0	OSTEOSARCOMA
F02M3.0	OSTEOSARCOMA
M03M3.0	OSTEOSARCOMA
M04M3.0	OSTEOSARCOMA
F05M3.0	OSTEOSARCOMA
M06M3.0	OSTEOSARCOMA
F07M3.0	OSTEOSARCOMA
F08M3.0	OSTEOSARCOMA
M09M3.0	OSTEOSARCOMA

DOG NUMBER	AT INJECTION		INJECTED ($\mu\text{C/KG}$)	DATE INJECTED			DAYS SINCE INJECTION 30/9/65 DEATH	DOSE TO SKELETON (RADS)
	AGE (DAYS)	WEIGHT (KG)		D	MO	YR		
M10M3.0	581	10.4	1.00	17	7	52	1171	
F11M3.0	499	11.0	1.19	18	9	52	1108	
M12M3.0	510	12.9	.987	23	10	52	1073	
F01M4.0	510	7.56	2.60	4	01	54	841	5614
F02M4.0	460	6.95	1.86	29	11	54	778	2272
M03M4.0	579	9.65	3.37	13	03	56	418	1795
M03M4.0A	494	7.34	2.64	4	06	57	1063	5604
M04M4.0	609	7.84	2.47	15	1	57	896	2680
F05M4.0	509	9.63	2.67	5	03	57	1064	4358
M06M4.0	502	9.49	2.66	23	04	57	1121	4784
F07M4.0	544	8.40	2.67	4	06	57	1253	4636
F01M5.0	494	7.77	8.11	4	01	54	232	3854
F02M5.0	460	7.35	5.46	29	11	54	780	7666
M03M5.0	579	8.87	10.4	13	3	56	688	14151
M04M5.0	482	7.29	7.89	15	01	57	561	5662
F05M5.0	658	11.1	8.48	5	3	57	770	9559
M06M5.0	580	7.53	8.67	23	4	57	792	6761
F07M5.0	494	7.35	8.92	4	06	57	966	18094

* ($\mu\text{C Th}^{228}/\mu\text{C Ra}^{228}$) 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 F1M0.5, F2M0.5, M3M0.5,
 F1M1A, F1M1.7 and M3M4.0A.

DOG
NUMBER

COMMENTS ON DEAD DOGS

M10M3.0
F11M3.0
M12M3.0

F01M4.0 OSTEOSARCOMA + CRIPPLING FRACTURE
F02M4.0 OSTEOSARCOMA
M03M4.0 STRANGULATED INGUINAL HERNIA
M03M4.0A OSTEOSARCOMA, NEPHRITIS, ULCERATIVE GINGIVITIS + PNEUMONIA
M04M4.0 FRACTURED MANDIBLE + ULCERATIVE GINGIVITIS
F05M4.0 OSTEOSARCOMA
M06M4.0 OSTEOSARCOMA
F07M4.0 OSTEOSARCOMA

F01M5.0 NEPHRITIS + SEVERE ANEMIA
F02M5.0 CRIPPLING FRACTURES
M03M5.0 ULCERATIVE GINGIVITIS
M04M5.0 CRIPPLING FRACTURE
F05M5.0 ULCERATIVE GINGIVITIS
M06M5.0 OSTEOSARCOMA + CRIPPLING FRACTURE
F07M5.0 ULCERATIVE GINGIVITIS, MYOCARDIAL INFARCTION + GLAUCOMA

D. THORIUM-228 (RADIOTHORIUM) *

DOG NUMBER	AT INJECTION		INJECTED (μ C/KG)	DATE INJECTED			DAYS SINCE INJECTION		DOSE TO SKELETON (RADS)
	AGE (DAYS)	WEIGHT (KG)		D	MO	YR	30/9/65	DEATH	
M01T0.0	493	8.24		8	02	54	4252		
M02T0.0	488	7.28		28	09	54	4020		
F03T0.0	797	11.6		6	06	55		2592	
M04T0.0	591	8.10		18	10	55		3072	
M05T0.0	458	10.4		14	10	58	2543		
F06T0.0	489	9.64		10	1	61		171	
F06T0.0A	688	8.61		15	12	60	1750		
M07T0.0	517	10.5		7	2	61		1412	
M08T0.0	533	10.8		24	5	61	1590		
F09T0.0	569	8.28		29	6	61	1554		
F10T0.0	536	10.4		28	7	61	1525		
F11T0.0	530	9.45		4	6	63	849		
F12T0.0	492	9.09		9	7	63	814		
M01T0.2	682	11.4	.00164	27	03	62	1283		
M02T0.2	682	10.4	.00166	27	03	62	1283		
F03T0.2	478	9.86	.00163	27	03	62	1283		
M04T0.2	478	10.0	.00166	27	03	62	1283		
M05T0.2	625	13.8	.00162	9	02	60		889	10
M05T0.2A	530	13.4	.00173	4	6	63	849		
F06T0.2	489	8.85	.00176	10	1	61	1724		
M07T0.2	532	10.5	.00159	7	2	61	1696		
M08T0.2	494	13.9	.00189	24	5	61	1590		
F09T0.2	569	7.82	.00171	29	6	61	1554		
F10T0.2	508	10.5	.00170	28	7	61	1525		
F11T0.2	530	9.76	.00171	4	6	63	849		
F12T0.2	492	7.37	.00190	9	7	63	814		
M01T0.5	699	14.3	.00496	7	9	56	3310		
M02T0.5	455	10.5	.00490	28	09	54		1976	41
F03T0.5	659	8.59	.00485	6	6	55		3032	44
M04T0.5	516	8.58	.00540	18	10	55		2159	46
M05T0.5	513	8.46	.00522	14	10	58	2543		
F06T0.5	489	9.66	.00510	10	1	61	1724		
M07T0.5	532	9.11	.00491	7	2	61	1696		
M08T0.5	533	9.53	.00562	24	5	61	1590		
F09T0.5	569	8.62	.00529	29	06	61	1554		
F10T0.5	508	10.2	.00510	28	7	61	1525		
F11T0.5	530	7.78	.00518	4	6	63	849		

DOG
NUMBER

COMMENTS ON DEAD DOGS

M01T0.0
M02T0.0
F03T0.0
M04T0.0
M05T0.0
F06T0.0
F06T0.0A
M07T0.0
M08T0.0
F09T0.0
F10T0.0
F11T0.0
F12T0.0

BRAIN HEMORRHAGE
LYMPHOSARCOMA

TRAUMA

BRAIN HEMORRHAGE

M01T0.2
M02T0.2
F03T0.2
M04T0.2
M05T0.2
M05T0.2A
F06T0.2
M07T0.2
M08T0.2
F09T0.2
F10T0.2
F11T0.2
F12T0.2

STRANGULATION ON VOMITUS + GRAND MAL

M01T0.5
M02T0.5
F03T0.5
M04T0.5
M05T0.5
F06T0.5
M07T0.5
M08T0.5
F09T0.5
F10T0.5
F11T0.5

STRANGULATION ON VOMITUS + GRAND MAL
PYOMETRITIS + SECONDARY PERITONITIS
STATUS EPILEPTICUS + PNEUMONIA

DOG NUMBER	AT INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (μ C/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 30/9/65 DEATH	DOSE TO SKELETON (RADS)
F12T0.5	492	9.94	.00567	9 7 63	814	
M01T1.0	493	9.36	.0146	8 02 54	3172	132
M02T1.0	699	9.27	.0146	7 09 56	3310	
F03T1.0	723	8.84	.0145	7 09 56	3310	
M04T1.0	699	8.27	.0146	7 09 56	3217	132
M05T1.0	513	11.9	.0146	14 10 58	2543	
F06T1.0	489	8.81	.0150	10 1 51	1724	
M07T1.0	532	9.18	.0147	7 2 51	1696	
M08T1.0	533	8.69	.0166	24 5 51	1590	
F09T1.0	527	10.0	.0160	29 6 51	1554	
F10T1.0	508	10.2	.0150	28 7 51	1525	
F11T1.0	521	7.55	.0154	4 6 53	849	
F12T1.0	472	9.96	.0167	9 7 53	814	
M01T1.5	699	7.95	.0289	7 9 56	2894	258
M02T1.5	458	10.0	.0293	28 09 54	2576	257
F03T1.5	609	10.3	.0303	6 06 55	1921	249
M04T1.5	591	8.59	.0299	18 10 55	2309	257
M05T1.5	598	9.65	.0286	9 2 50	1624	223
F06T1.5	489	8.14	.0292	10 1 51	1724	
M07T1.5	517	8.83	.0292	7 2 51	384	95
M07T1.5A	521	9.08	.0311	4 6 53	849	
M08T1.5	494	11.6	.0324	24 5 51	1590	
F09T1.5	527	8.80	.0306	29 6 51	1554	
F10T1.5	508	11.6	.0296	28 7 51	1525	
F11T1.5	518	11.4	.0305	4 6 53	849	
F12T1.5	465	7.56	.0329	9 7 53	814	
M01T2.0	491	10.2	.0976	8 02 54	1282	693
M02T2.0	483	9.16	.0875	28 09 54	1234	611
F03T2.0	474	7.87	.0908	6 06 55	1541	695
M04T2.0	553	13.0	.0900	18 10 55	78	70
M04T2.0A	650	10.6	.0899	7 09 56	1222	625
M05T2.0	598	9.12	.0848	9 02 50	1085	556
F06T2.0	451	8.65	.0879	10 1 51	1108	583
M07T2.0	517	8.85	.0881	7 2 51	1015	558

DOG
NUMBER

COMMENTS ON DEAD DOGS

F12T0.5

M01T1.0	OSTEOSARCOMA
M02T1.0	
F03T1.0	
M04T1.0	OSTEOSARCOMA THYROID CARCINOMA PERIANAL ADENOCARCINOMA
M05T1.0	
F06T1.0	
M07T1.0	
M08T1.0	
F09T1.0	
F10T1.0	
F11T1.0	
F12T1.0	

M01T1.5	OSTEOSARCOMA
M02T1.5	OSTEOSARCOMA
F03T1.5	COMA OF UNKNOWN ETIOLOGY
M04T1.5	OSTEOSARCOMA
M05T1.5	OSTEOSARCOMA
F06T1.5	
M07T1.5	LEPTOSPIROSIS
M07T1.5A	
M08T1.5	
F09T1.5	
F10T1.5	
F11T1.5	
F12T1.5	

M01T2.0	OSTEOSARCOMA
M02T2.0	OSTEOSARCOMA
F03T2.0	OSTEOSARCOMA
M04T2.0	TRAUMA
M04T2.0A	OSTEOSARCOMA
M05T2.0	OSTEOSARCOMA
F06T2.0	OSTEOSARCOMA
M07T2.0	OSTEOSARCOMA

DOG NUMBER	AT INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (μ C/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 30/9/65 DEATH	DOSE TO SKELETON (RADS)
M08T2.0	533	10.7	.0981	24 5 61	1078	641
F09T2.0	527	8.09	.0979	29 6 61	1209	677
F10T2.0	508	10.7	.0919	28 7 61	1022	584
F11T2.0	518	10.8	.0904	4 6 63	849	
F12T2.0	464	8.92	.100	9 7 63	814	
M01T3.0	314	9.15	.301	8 02 54	988	1879
M02T3.0	458	11.9	.301	28 09 54	859	1736
F03T3.0	471	12.0	.272	6 06 55	547	1164
M04T3.0	606	9.69	.285	18 10 55	801	1575
M05T3.0	571	10.7	.269	9 02 50	890	1584
F06T3.0	451	8.83	.282	10 1 61	1156	1909
M07T3.0	427	9.90	.266	7 2 61	861	1536
M08T3.0	494	10.1	.313	24 5 61	685	1566
F09T3.0	511	11.5	.298	29 6 61	1062	1933
F10T3.0	508	9.26	.280	28 7 61	971	1732
F11T3.0	518	10.3	.290	4 6 63	791	1591
F12T3.0	459	11.5	.320	9 7 63	804	1773
M01T4.0	480	8.32	.882	8 02 54	645	4237
M02T4.0	458	8.32	.916	28 09 54	833	5185
F03T4.0	461	7.25	.800	6 06 55	763	4290
M04T4.0	606	8.81	.835	18 10 55	793	4587
M01T5.0	480	9.48	2.76	8 02 54	212	5457
M02T5.0	483	8.22	2.63	28 09 54	97	2535

DOG
NUMBER

COMMENTS ON DEAD DOGS

M08T2.0 OSTEOSARCOMA
F09T2.0 OSTEOSARCOMA
F10T2.0 OSTEOSARCOMA
F11T2.0
F12T2.0

M01T3.0 OSTEOSARCOMA + SEVERE ANEMIA
M02T3.0 OSTEOSARCOMA + TRAUMA
F03T3.0 OSTEOSARCOMA
M04T3.0 OSTEOSARCOMA
M05T3.0 OSTEOSARCOMA
F06T3.0 OSTEOSARCOMA
M07T3.0 OSTEOSARCOMA
M08T3.0 OSTEOSARCOMA
F09T3.0 OSTEOSARCOMA
F10T3.0 OSTEOSARCOMA
F11T3.0 OSTEOSARCOMA
F12T3.0 HEMANGIOSARCOMA

M01T4.0 OSTEOSARCOMA + CRIPPLING FRACTURE
M02T4.0 OSTEOSARCOMA, CRIPPLING FRACTURE + NEPHRITIS
F03T4.0 ULCERATIVE GINGIVITIS + NEPHRITIS
M04T4.0 ULCERATIVE GINGIVITIS

M01T5.0 NEPHRITIS
M02T5.0 PANCYTOPENIA

E. STRONTIUM-90

DOG NUMBER	AT INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (μ C/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 30/9/65	DEATH	DOSE TO SKELETON (RADS)
F01S0.0	502	8.48		18 01 55	3908		
M02S0.0	600	11.1		14 02 56	3516		
M03S0.0	493	9.03		11 09 57	2941		
F04S0.0	520	8.19		15 10 57	2907		
M05S0.0	542	10.6		19 11 57	2872		
M06S0.0	466	9.68		27 05 58	2683		
F07S0.0A	462	9.46		7 01 59	2458		
F08S0.0	483	9.29		19 05 59	2326		
F09S0.0	549	12.4		11 08 59		708	
F09S0.0A	535	11.2		4 5 63	849		
M10S0.0	522	13.9		29 09 59	2193		
F11S0.0	541	9.60		3 11 59	2158		
M12S0.0	605	8.99		6 01 60	2094		
F01S1.0	1524	6.84	.573	18 01 55		308	21
F01S1.0A	521	9.38	.588	14 02 56	3516		
M02S1.0	567	8.81	.606	14 02 56	3516		
M03S1.0	493	10.9	.572	11 09 57	2941		
F04S1.0	525	8.96	.560	15 10 57	2907		
M05S1.0	555	10.2	.532	19 11 57		2705	69
M06S1.0	466	9.56	.581	27 05 58	2683		
F07S1.0	524	9.94	.517	11 11 58	2515		
F08S1.0	483	10.8	.697	19 05 59	2326		
F09S1.0	549	11.6	.534	11 08 59	2242		
M10S1.0	522	11.5	.558	29 09 59	2193		
F11S1.0	543	10.3	.550	3 11 59	2158		
M12S1.0	607	13.7	.559	6 01 60	2094		
F01S1.7	526	7.41	1.78	14 02 56	3516		
M02S1.7	567	11.6	1.84	14 02 56	3516		
M03S1.7	493	9.19	1.69	11 09 57	2941		
F04S1.7	522	9.60	1.68	15 10 57	2907		
M05S1.7	560	9.85	1.60	19 11 57		1715	161
M05S1.7A	493	11.4	1.78	6 3 63	939		
M06S1.7	466	10.6	1.72	27 05 58	2683		
F07S1.7	488	10.2	1.60	11 11 58	2515		
F08S1.7	472	8.47	2.03	19 5 59		1973	215
F09S1.7	549	10.0	1.62	11 08 59	2242		
M10S1.7	519	13.6	1.66	29 09 59	2193		

DOG
NUMBER

COMMENTS ON DEAD DOGS

F01S0.0
M02S0.0
M03S0.0
F04S0.0
M05S0.0
M06S0.0
F07S0.0A
F08S0.0
F09S0.0
F09S0.0A
M10S0.0
F11S0.0
M12S0.0

TRAUMA

F01S1.0 SACRIFICED -IMPROPER INJECTION AGE-
F01S1.0A
M02S1.0
M03S1.0
F04S1.0
M05S1.0 STATUS EPILEPTICUS
M06S1.0
F07S1.0
F08S1.0
F09S1.0
M10S1.0
F11S1.0
M12S1.0

F01S1.7
M02S1.7
M03S1.7
F04S1.7
M05S1.7 COMA OF UNKNOWN ETIOLOGY
M05S1.7A
M06S1.7
F07S1.7
F08S1.7 STATUS EPILEPTICUS, CHRONIC PANCREATITIS
F09S1.7
M10S1.7

DOG NUMBER	AT INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (μ C/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 30/9/65 DEATH	DOSE TO SKELETON (RADS)
F11S1.7	543	11.0	1.68	3 11 59	2158	
M12S1.7	607	11.9	1.68	6 01 60	2094	
F01S2.0	502	5.59	3.70	18 1 55	3269	480
M02S2.0	567	8.97	3.42	14 02 56	3516	
M03S2.0	494	7.82	3.39	11 09 57	2941	
F04S2.0	522	9.68	3.41	15 10 57	2907	
M05S2.0	560	8.72	3.24	19 11 57	2872	
M06S2.0	466	9.19	3.50	27 05 58	2683	
F07S2.0	488	11.2	3.19	11 11 58	2515	
F08S2.0	465	9.49	4.14	19 05 59	2326	
F09S2.0	473	14.1	3.28	11 08 59	2242	
M10S2.0	508	10.7	3.34	29 09 59	2193	
F11S2.0	543	10.4	3.41	3 11 59	2158	
M12S2.0	607	11.6	3.49	6 01 60	2094	
F01S3.0	468	7.36	11.6	18 01 55	3908	
M02S3.0	565	9.62	11.6	14 02 56	3516	
M03S3.0	494	11.4	10.8	11 09 57	2941	
F04S3.0	527	9.17	10.6	15 10 57	2907	
M05S3.0	557	8.90	10.1	19 11 57	2872	
M06S3.0	466	9.44	10.9	27 05 58	2683	
F07S3.0	486	9.80	10.1	11 11 58	2515	
F08S3.0	465	12.5	12.9	19 05 59	2326	
F09S3.0	468	10.0	10.1	11 08 59	2242	
M10S3.0	519	12.5	10.3	29 09 59	2193	
F11S3.0	541	9.00	10.8	3 11 59	2158	
M12S3.0	605	8.43	10.2	6 01 60	2094	
F01S4.0	468	8.74	33.3	18 01 55	3682	6832
M02S4.0	567	11.2	32.6	14 02 56	2093	5806
M03S4.0	593	9.83	32.1	11 09 57	2781	4052
F04S4.0	528	8.24	32.1	15 10 57	2907	
M05S4.0	562	9.65	30.6	19 11 57	2872	
M06S4.0	504	16.0	32.7	3 09 58	2584	
F07S4.0	478	10.9	30.9	11 11 58	2515	
F08S4.0	465	10.9	40.6	19 05 59	2206	7801

DOG
NUMBER

COMMENTS ON DEAD DOGS

F11S1.7
M12S1.7

F01S2.0 BACTERIAL PNEUMONIA
M02S2.0
M03S2.0
F04S2.0
M05S2.0
M06S2.0
F07S2.0
F08S2.0
F09S2.0
M10S2.0
F11S2.0
M12S2.0

F01S3.0
M02S3.0
M03S3.0
F04S3.0
M05S3.0
M06S3.0
F07S3.0
F08S3.0
F09S3.0
M10S3.0
F11S3.0
M12S3.0

F01S4.0 NOT DETERMINED (NO OSTEOSARCOMA)
M02S4.0 SQUAMOUS CELL CARCINOMA -GINGIVA-
M03S4.0 OBTURATING PULMONARY EMBOLISM
F04S4.0
M05S4.0
M06S4.0
F07S4.0
F08S4.0 UNDETERMINED

DOG NUMBER	AT INJECTION			DATE INJECTED			DAYS SINCE INJECTION 30/9/65 DEATH	DOSE TO SKELETON (RADS)
	AGE (DAYS)	WEIGHT (KG)	INJECTED (μ C/KG)	D	MO	YR		
F09S4.0	468	9.56	30.6	11	08	59	2242	
M10S4.0	517	8.20	31.3	29	09	59	2193	
F11S4.0	542	8.86	32.7	3	11	59	2114	3324
M12S4.0	605	10.9	32.3	6	01	60	2094	
F01S5.0	434	9.38	103.	18	01	55	960	8127
M02S5.0	551	12.2	102.	14	02	56	255	3202
M02S5.0A	545	11.4	96.6	7	1	59	1740	12007
M03S5.0	507	10.3	102.	15	10	57	2256	16297
F04S5.0	528	11.4	105.	15	10	57	1448	9281
M05S5.0	621	8.53	95.2	19	11	57	1285	9930
M06S5.0	504	9.33	98.8	3	9	58	35	647
M06S5.0A	462	11.2	94.2	7	01	59	1021	11616
F07S5.0	478	10.2	92.7	11	11	58	1129	10822
F08S5.0	535	11.2	90.5	7	01	59	1469	10941
F09S5.0	459	8.82	93.5	11	08	59	1982	13569
M10S5.0	517	8.55	95.9	29	09	59	990	7744
F11S5.0	542	8.97	102.	3	11	59	1667	9956
M12S5.0	606	12.5	99.2	6	01	60	1165	8327

DOG
NUMBER

COMMENTS ON DEAD DOGS

F09S4.0
M10S4.0
F11S4.0
M12S4.0

PYOMETRA COMPLICATIONS

F01S5.0 OSTEOSARCOMA
M02S5.0 STRANGULATED INGUINAL HERNIA
M02S5.0A OSTEOSARCOMA
M03S5.0 OSTEOSARCOMA
F04S5.0 OSTEOSARCOMA
M05S5.0 SEVERE ANEMIA, AUTOAGGLUTINATION, INFARCTION, SPLENOMEGALY
M06S5.0 INTESTINAL HEMORRHAGE
M06S5.0A OSTEOSARCOMA, INFARCTION + THROMBOCYTOPENIA
F07S5.0 STATUS EPILEPTICUS
F08S5.0 OSTEOSARCOMA
F09S5.0 SQUAMOUS CELL CARCINOMA ARISING FROM FRONTAL SINUS
M10S5.0 SEVERE ANEMIA + THROMBOCYTOPENIA
F11S5.0 HEMANGIOSARCOMA (LEFT MANDIBLE)
M12S5.0 HEMANGIOSARCOMA (RIB)

* TABLE II. TEST ANIMALS (SEPT. 30, 1965)

A. RADIUM-226*

DOG NUMBER	AT INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (μ C/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 30/9/65	DEATH	DOSE TO SKELETON (RADS)
T01R5.0	995	11.1	10.3	1 12 52		1074	9469
T02R5.0	919	8.40	4.39	12 01 53		1368	4724
T03R5.0	1467	8.29	4.76	12 01 53		428	1316
T04R5.0	459	10.0	10.6	6 07 53		1	24
T05R5.0	126	6.14	11.7	6 10 53		1	25
T06R5.0	126	6.14	11.4	6 10 53		1	24
T07R5.0	126	6.14	11.8	6 10 53		1	25
T08R5.0	290	5.52	1.92	10 05 55		58	488
T09R5.0	2276	10.4	1.94	10 05 55		58	585
T10R5.0	43	1.02	1.98	10 05 55		49	293
T11R5.0	43	1.58	1.91	10 05 55		49	363
T12R5.0	397	12.3	9.72	9 05 56		225	2707
T13R5.0	397	7.59	9.76	9 05 56		188	2319
T14R4.0	674	8.12	3.17	11 07 56		72	380
T15R4.0	672	9.03	3.11	11 07 56		2127	5117
T16R5.0	604	12.4	9.68	11 07 57		12	183
T17R5.0H	383	12.2	9.87	28 10 58		1147	13655
T18R5.0H	383	11.1	10.8	28 10 58		1226	12628
T19R5.0H	383	11.3	10.7	28 10 58		1219	11580
T20R5.0H	383	11.4	10.6	28 10 58		1330	12937
T21R5.0H	381	11.8	10.1	28 10 58		386	3710
T22R5.0H	381	11.9	10.1	28 10 58		587	5911
T23R4.0H	384	9.50	4.05	25 11 58		1471	4340
T24R4.0H	384	11.9	3.24	25 11 58		1505	5593
T25R4.0H	379	11.3	3.42	25 11 58		1309	4672
T26R4.0H	379	11.0	3.48	25 11 58		1780	4719
T27R4.0H	372	11.5	3.34	25 11 58		1414	3382
T28R3.0H	372	11.7	1.11	25 11 58		387	357
T29R5.0	474	13.5	10.4	3 03 59		216	3404

DOG
NUMBER

COMMENTS ON DEAD DOGS

T01R5.0 OSTEOSARCOMA
T02R5.0 OSTEOSARCOMA
T03R5.0 SPECIAL STUDY
T04R5.0 SPECIAL STUDY
T05R5.0 SPECIAL STUDY
T06R5.0 SPECIAL STUDY
T07R5.0 SPECIAL STUDY
T08R5.0 SPECIAL STUDY
T09R5.0 SPECIAL STUDY
T10R5.0 SPECIAL STUDY
T11R5.0 SPECIAL STUDY
T12R5.0 SPECIAL STUDY
T13R5.0 SPECIAL STUDY

T14R4.0 SPECIAL STUDY
T15R4.0 OSTEOSARCOMA

T16R5.0 SPECIAL STUDY
T17R5.0H OSTEOSARCOMA + ULCERATIVE GINGIVITIS
T18R5.0H OSTEOSARCOMA + ULCERATIVE GINGIVITIS
T19R5.0H OSTEOSARCOMA + ULCERATIVE GINGIVITIS
T20R5.0H OSTEOSARCOMA + ULCERATIVE GINGIVITIS
T21R5.0H NEPHRITIS
T22R5.0H CRIPPLING FRACTURES

T23R4.0H OSTEOSARCOMA
T24R4.0H OSTEOSARCOMA
T25R4.0H OSTEOSARCOMA
T26R4.0H OSTEOSARCOMA
T27R4.0H OSTEOSARCOMA

T28R3.0H SPECIAL STUDY

T29R5.0 NEPHRITIS

DOG NUMBER	AT INJECTION		INJECTED (μ C/KG)	DATE INJECTED			DAYS SINCE INJECTION		DOSE TO SKELETON (RADS)
	AGE (DAYS)	WEIGHT (KG)		D	MO	YR	30/9/65	DEATH	
T30R5.0	474	11.5	10.4	3	03	59		178	2851
T31R5.0	471	10.5	10.4	3	03	59		303	4758
T32R3.0	471	11.4	1.13	3	03	59		2294	1864
T33R3.0	471	10.6	1.15	3	3	59		1822	1921
T34R3.0	470	15.7	1.12	3	3	59		1737	1603
T35R3.0J	670	9.44	.951	5	5	59		8	14
T36R4.0	695	10.2	2.99	22	12	60		1154	3647
T37R4.0	695	9.53	3.00	22	12	60		1627	3234
T38R4.0	695	10.1	3.02	22	12	60		1503	3657
T40R1.0	899	13.0	.0483	3	4	62		7	1
T41R1.0	899	12.7	.0487	3	4	62		63	3
T42R1.7	967	14.0	.146	4	4	62		7	2
T43R1.7	963	13.2	.145	4	4	62		64	11
T44R3.0	938	11.1	.937	4	4	62		68	71
T45R3.0	939	13.6	.941	5	4	62		7	12
T46R3.0	810	12.5	.928	5	4	62		69	103
T47R6.0	99	5.27	29.4	11	6	62		4	352
T48R6.0	2842	11.2	25.1	27	12	62		49	1597
T49R5.0	485	10.6	7.54	2	5	63		5	111
T50R5.0	485	13.7	7.46	2	5	63		15	274
T51R5.0	418	13.3	8.48	8	5	63		92	1689
T52R5.0	418	10.7	8.57	8	5	63		15	258

DOG
NUMBER

COMMENTS ON DEAD DOGS

T30R5.0 NEPHRITIS
T31R5.0 NEPHRITIS

T32R3.0 OSTEOSARCOMA
T33R3.0 OSTEOSARCOMA, NEPHRITIS
T34R3.0 OSTEOSARCOMA
T35R3.0J SPECIAL STUDY

T36R4.0 OSTEOSARCOMA
T37R4.0 OSTEOSARCOMA
T38R4.0 OSTEOSARCOMA

T40R1.0 SPECIAL STUDY
T41R1.0 SPECIAL STUDY

T42R1.7 SPECIAL STUDY
T43R1.7 SPECIAL STUDY

T44R3.0 SPECIAL STUDY
T45R3.0 SPECIAL STUDY
T46R3.0 SPECIAL STUDY

T47R6.0 SPECIAL STUDY
T48R6.0 LEUKOPENIA, PNEUMONIA + SPECIAL MELANOMA STUDY

T49R5.0 SPECIAL STUDY
T50R5.0 SPECIAL STUDY
T51R5.0 SPECIAL STUDY
T52R5.0 SPECIAL STUDY

DOG NUMBER	AT INJECTION		INJECTED (μ C/KG)	DATE INJECTED			DAYS SINCE INJECTION 30/9/65 DEATH	DOSE TO SKELETON (RADS)
	AGE (DAYS)	WEIGHT (KG)		D	MO	YR		
T53R5.0	418	12.0	8.50	8	5	63	33	611
T54R5.0	417	11.4	8.76	22	5	63	5	88
T55R5.0	417	11.6	8.61	22	5	63	33	534
T56R5.0	417	11.6	8.61	22	5	63	90	1461
T57R4.0	501	12.1	2.72	15	8	63	14	54
T58R4.0	496	11.7	2.41	15	8	63	61	286
T59R4.0	496	9.64	2.57	15	8	63	63	272
T60R4.0	490	12.1	2.33	15	8	63	117	415
T61R4.0	490	9.48	2.70	15	8	63	371	1567
T62R4.0	490	8.63	2.68	15	8	63	460	1586
T63R3.0	559	8.72	.899	29	1	64	36	51
T64R3.0	551	8.42	.919	29	1	64	63	73
T65R3.0	551	11.6	.922	29	1	64	70	99
T66R3.0	549	10.1	.904	29	1	64	132	140
T67R3.0	549	12.7	.898	29	1	64	134	168
T68R3.0	549	12.1	.917	29	1	64	610	
T69R3.0	499	8.84	.919	29	1	64	610	
T70R3.0	499	14.2	.922	29	1	64	610	

*. 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 Ra^{226} injection was 20.0 μ C for the dogs T17R5H - T22R5H; 6.41 μ C for T23R4H - T27R4H; and 2.16 μ C for T28R3H. Tabulated for each dog are his age at 1st injection, his average weight during the injection period, total μ C/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 received 99 μ C Sr^{85} .

T39R0.0 has been reassigned and is now M12M0.0.

DOG
NUMBER

COMMENTS ON DEAD DOGS

T53R5.0	SPECIAL STUDY
T54R5.0	SPECIAL STUDY
T55R5.0	SPECIAL STUDY
T56R5.0	SPECIAL STUDY

T57R4.0	SPECIAL STUDY
T58R4.0	SPECIAL STUDY
T59R4.0	SPECIAL STUDY
T60R4.0	SPECIAL STUDY
T61R4.0	SPECIAL STUDY
T62R4.0	SPECIAL STUDY

T63R3.0	SPECIAL STUDY
T64R3.0	SPECIAL STUDY
T65R3.0	SPECIAL STUDY
T66R3.0	SPECIAL STUDY
T67R3.0	SPECIAL STUDY
T68R3.0	
T69R3.0	
T70R3.0	

B. PLUTONIUM-239

DOG NUMBER	AT INJECTION		INJECTED ($\mu\text{C/KG}$)	DATE INJECTED			DAYS SINCE INJECTION		DOSE TO SKELETON (RADS)
	AGE (DAYS)	WEIGHT (KG)		D	MO	YR	30/9/65	DEATH	
T00P5.0	647	11.4	3.05	24	06	52		1	10
T01P5.0	581	12.7	3.04	13	10	52		29	160
T02P5.0	914	11.9	6.85	15	09	52		44	520
T03P5.0	942	9.65	3.22	13	10	52		610	3040
T04P5.0	1016	8.78	3.02	13	10	52		365	1750
T05P5.0	474	10.4	2.69	14	12	54		400	1720
T06P5.0	527	6.16	2.73	14	12	54		406	1750
T07P5.0	475	7.40	2.68	14	12	54		777	3230
T08P5.0	527	8.32	2.67	14	12	54		863	3540
T09P5.0	551	10.3	2.80	22	11	55		15	80
T10P5.0	534	11.9	2.74	23	11	55		15	70
T11P5.0	516	12.1	2.76	22	11	55		28	140
T12P5.0	487	9.23	2.74	23	11	55		28	140
T13P5.0	587	8.27	3.16	24	04	56		3	20
T14P5.0	587	9.38	2.43	24	04	56		7	30
T15P5.0	737	8.32	2.79	15	10	56		1	10
T16P5.0	673	10.7	2.85	10	10	56		92	440
T17P5.0	739	11.1	3.01	12	02	57		210	990
T18P5.0	739	8.16	2.83	12	02	57		217	960
T19P5.0	688	8.86	2.91	15	12	50		1400	6129
T20P5.0	688	13.0	2.68	15	12	50		474	1970
T21P5.0	688	10.3	2.72	15	12	50		939	3940
T23P1.0	1485	13.1	.0172	28	7	51		96	3
T24P1.0	559	13.1	.0172	28	7	51		97	3
T25P1.0	559	13.8	.0167	28	7	51		467	10
T26P1.0	556	12.0	.0160	28	7	51		647	20
T27P3.0	556	11.5	.332	28	7	51		755	390
T28P1.0	552	10.5	.0150	9	8	51		559	10
T29P3.0	552	12.1	.296	9	8	51		560	260
T30P1.0	548	12.4	.0148	9	8	51		35	1

DOG
NUMBER

COMMENTS ON DEAD DOGS

T00P5.0	SPECIAL STUDY
T01P5.0	SPECIAL STUDY
T02P5.0	SPECIAL STUDY
T03P5.0	SPECIAL STUDY
T04P5.0	SPECIAL STUDY
T05P5.0	SPECIAL STUDY
T06P5.0	SPECIAL STUDY
T07P5.0	SPECIAL STUDY
T08P5.0	SPECIAL STUDY
T09P5.0	SPECIAL STUDY
T10P5.0	SPECIAL STUDY
T11P5.0	SPECIAL STUDY
T12P5.0	SPECIAL STUDY
T13P5.0	SPECIAL STUDY
T14P5.0	SPECIAL STUDY
T15P5.0	SPECIAL STUDY
T16P5.0	SPECIAL STUDY
T17P5.0	SPECIAL STUDY
T18P5.0	SPECIAL STUDY
T19P5.0	OSTEOSARCOMA, BLOOD DYSCRASIA, LIVER DEGENERATION
T20P5.0	LIVER DEGENERATION, ASCITES + THROMBOCYTOPENIA
T21P5.0	TOXIC NEPHRITIS + LIVER DEGENERATION

T23P1.0	SPECIAL STUDY
T24P1.0	SPECIAL STUDY
T25P1.0	SPECIAL STUDY
T26P1.0	SPECIAL STUDY

T27P3.0	SPECIAL STUDY
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T28P1.0	SPECIAL STUDY
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T29P3.0	SPECIAL STUDY
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T30P1.0	SPECIAL STUDY
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DOG NUMBER	AT INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (μ C/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 30/9/65 DEATH	DOSE TO SKELETON (RADS)
T31P3.0	519	13.0	.305	9 8 61	40	20
T32P1.0	520	8.47	.0162	9 8 61	274	10
T33P1.0	550	10.7	.0153	15 9 61	375	10
T34P1.0	550	9.68	.0154	15 9 61	746	20
T35P3.0	550	11.9	.303	15 9 61	362	180
T36P1.0	544	10.4	.0158	15 9 61	5	
T37P1.0	542	8.59	.0148	15 9 61	186	4
T38P3.0	489	7.96	.304	15 9 61	187	90
T39P1.0	1534	10.7	.0151	15 9 61	376	10
T40P1.0	1534	9.92	.0177	15 9 61	769	20
T41P5.0	543	8.50	3.01	30 11 64	304	
T42P5.0	510	11.4	2.40	10 2 55	13	57
T43P5.0H	600	14.0	2.86	15 7 55	40	200
T44P5.0	517	12.0	2.72	21 9 55	9	

T22P0.0 has been reassigned and is now F06T0.0A.

DOG
NUMBER

COMMENTS ON DEAD DOGS

T31P3.0 : SPECIAL STUDY

T32P1.0 : SPECIAL STUDY

T33P1.0 : SPECIAL STUDY

T34P1.0 : SPECIAL STUDY

T35P3.0 : SPECIAL STUDY

T36P1.0 : SPECIAL STUDY

T37P1.0 : SPECIAL STUDY

T38P3.0 : SPECIAL STUDY

T39P1.0 : SPECIAL STUDY

T40P1.0 : SPECIAL STUDY

T41P5.0 :

T42P5.0 : SPECIAL STUDY

T43P5.0H : SPECIAL STUDY

T44P5.0

C. RADIUM-228 (MESOTHORIUM)*

DOG NUMBER	AT INJECTION			DATE			DAYS SINCE INJECTION 30/9/65 DEATH	DOSE TO SKELETON (RADS)
	AGE (DAYS)	WEIGHT (KG)	INJECTED ($\mu\text{C/KG}$)	INJECTED	D	MO YR		
T01M4.5	529	9.13	4.23	8	09	54	314	1598
T02M4.5	463	8.93	4.27	8	09	54	755	5097
T03M5.0	579	9.15	10.6	13	03	56	700	15867

* ($\mu\text{C Th}^{228} / \mu\text{C Ra}^{228}$) injected = 0.03.

DOG
NUMBER

COMMENTS ON DEAD DOGS

T01M4.5 CANINE DISTEMPER
T02M4.5 SPECIAL STUDY

T03M5.0 ULCERATIVE GINGIVITIS, SEVERE ANEMIA + CRIPPLING FRACTURE

D. THORIUM-228 (RADIOTHORIUM)*

DOG NUMBER	AT INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED ($\mu\text{C/KG}$)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 30/9/65 DEATH	DOSE TO SKELETON (RADS)
T01T5.0	490	9.30	4.88	1 12 53	23	1161
T02T5.0	501	8.48	2.56	8 02 54	77	1979
T03T4.0	429	10.4	.870	8 02 54	820	4878
T04T5.0	455	8.92	2.59	28 09 54	113	2883
T05T5.0	455	10.1	2.32	28 09 54	65	1524
T06T4.0	591	7.01	.884	18 10 55	651	4273
T07T3.0	591	9.23	.298	18 10 55	910	1777
T08T3.0	606	9.23	.293	14 10 58	1043	1883
T09T3.0	447	11.0	.285	4 02 59	1	3
T10T3.0	447	14.2	.289	4 02 59	8	24
T11T3.0	500	8.62	.335	16 6 59	22	76
T12T3.0	514	10.6	.302	7 7 59	22	69
T13T3.0	754	13.1	.298	28 7 59	22	68

*T11, 12, 13T3 received 40, 4, and 0.4 mg Th^{232} , respectively.

DOG NUMBER	COMMENTS ON DEAD DOGS
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T01T5.0	DIED, SPECIAL STUDY
T02T5.0	SPECIAL STUDY

T03T4.0	CRIPPLING FRACTURES + NEPHRITIS
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T04T5.0	THROMBOCYTOPENIA + PURPURA
T05T5.0	NEPHRITIS, THROMBOCYTOPENIA + PURPURA

T06T4.0	CRIPPLING FRACTURES
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T07T3.0	SPECIAL STUDY
T08T3.0	OSTEOSARCOMA
T09T3.0	SPECIAL STUDY
T10T3.0	SPECIAL STUDY
T11T3.0	SPECIAL STUDY
T12T3.0	SPECIAL STUDY
T13T3.0	SPECIAL STUDY

E. STRONTIUM-90*

DOG NUMBER	AT INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED ($\mu\text{C}/\text{KG}$)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 30/9/65 DEATH	DOSE TO SKELETON (RADS)
T01S0.0	151	7.71		5 03 54	2	
T02S5.0	149	6.85	148.	5 03 54	11	626
T03S5.0	144	6.19	148.	5 03 54	18	957
T04S5.0	151	7.05	148.	5 03 54	41	1945
T05S5.0	144	5.25	148.	5 03 54	116	4863
T06S5.0	155	7.01	87.0	16 03 54		2
T07S5.0	155	6.74	87.0	16 03 54	2	84
T08S0.0	243	7.00				
T08S2.0H	67	3.69	2.74	27 09 55	66	31
T09S2.0H	67	2.79	3.62	27 09 55	66	40
T10S2.0H	67	3.11	3.25	27 09 55	132	93
T11S2.0H	67	3.85	2.62	27 09 55	132	75
T12S3.0	593	10.6	10.5	11 09 57	5	15
T13S4.0	324	10.5	19.1	8 07 60	8	50
T14S5.0	542	10.0	96.1	7 11 61	9	175
T15S5.0	595	9.43	98.4	7 11 61	30	423
T16S2.0	604	9.71	3.27	8 11 61	9	6
T17S6.0	670	7.18	295.	19 1 62	14	689
T18S6.0	670	5.94	302.	19 1 62	1350	

DOG NUMBER	COMMENTS ON DEAD DOGS
---------------	-----------------------

T01S0.0	SPECIAL STUDY
---------	---------------

T02S5.0	SPECIAL STUDY
---------	---------------

T03S5.0	SPECIAL STUDY
---------	---------------

T04S5.0	SPECIAL STUDY
---------	---------------

T05S5.0	SPECIAL STUDY
---------	---------------

T06S5.0	SPECIAL STUDY
---------	---------------

T07S5.0	SPECIAL STUDY
---------	---------------

T08S .0	SPECIAL STUDY
---------	---------------

T08S2.0H	SPECIAL STUDY
----------	---------------

T09S2.0H	SPECIAL STUDY
----------	---------------

T10S2.0H	SPECIAL STUDY
----------	---------------

T11S2.0H	SPECIAL STUDY
----------	---------------

T12S3.0	BREMSSTRAHLUNG. PHANTOM
---------	-------------------------

T13S4.0	BREMSSTRAHLUNG PHANTOM SAM MCGEE
---------	----------------------------------

T14S5.0	SPECIAL STUDY
---------	---------------

T15S5.0	SPECIAL STUDY
---------	---------------

T16S2.0	SPECIAL STUDY
---------	---------------

T17S6.0	LEUKOPENIA, THROMBOCYTOPENIA + PURPURA
---------	--

T18S6.0	
---------	--

DOG NUMBER	AT INJECTION		INJECTED ($\mu\text{C/KG}$)	DATE INJECTED			DAYS SINCE INJECTION		DOSE TO SKELETON (RADS)
	AGE (DAYS)	WEIGHT (KG)		D	MO	YR	30/9/65	DEATH	
T19S6.0	670	5.43	284.	19	1	62		24	637
T20S4.0J	440	8.54	28.9	2	10	63		13	78
T21S2.5J	363	7.20	8.3	2	10	63		13	143

*T08 ... 11S2.0H were given 10 injections, 1 μC each at weekly intervals. Age is at first injection, wt. is average during the injection period, $\mu\text{C/kg}$ is total Sr^{90} /average weight, date is at first injection, days are from first injection to death, and dose is computed from mid-injection to death.

T20S4.0J received 0.5 μC Sr^{85} .

T21S2.5J received 0.5 μC Sr^{85} and 600 μC Sr^{89} .

DOG
NUMBER

COMMENTS ON DEAD DOGS

T19S6.0 LEUKOPENIA, THROMBOCYTOPENIA + PURPURA

T20S4.0J SPECIAL STUDY

T21S2.5J SPECIAL STUDY

F. RADIUM-224*

DOG NUMBER	AT INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED ($\mu\text{C/KG}$)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 30/9/65	DEATH	DOSE TO SKELETON (RADS)
T01Q3.0J	460	9.55	.875	26 3 63		4 hr	
T02Q4.0	466	12.0	2.91	27 3 63	918		
T03Q4.0	466	13.1	2.91	27 3 63	918		
T04Q5.0	480	9.55	9.71	24 4 63	890		
T05Q5.0	455	9.67	9.59	24 4 63	890		
T06Q6.0	455	8.29	24.6	17 10 63		13	980
T07Q5.0	465	11.8	9.83	6 11 63	694		
T08Q5.0	475	9.77	9.91	6 11 63		16	400
T09Q4.0	503	9.80	2.96	4 12 63	666		
T10Q4.0	503	10.3	2.96	4 12 63		262	133
T11Q3.0	495	9.10	1.02	4 12 63	666		
T12Q3.0	495	13.5	1.02	4 12 63	666		
T13Q3.0	495	11.3	1.02	4 12 63	666		
T14Q3.0	438	10.3	1.00	4 12 63	666		

*T01Q3.0J received 18.0 μC Sr^{85} .

DOG
NUMBER

COMMENTS ON DEAD DOGS

T01Q3.0J SPECIAL STUDY

T02Q4.0
T03Q4.0

T04Q5.0
T05Q5.0

T06Q6.0 PURPURA HEMORRHAGICA

T07Q5.0
T08Q5.0 PURPURA HEMORRHAGICA

T09Q4.0
T10Q4.0 STATUS EPILEPTICUS

T11Q3.0
T12Q3.0
T13Q3.0
T14Q3.0

G. ANCILLARY

DOG NUMBER	AT INJECTION		INJECTED (μ C/KG)	DATE INJECTED		DAYS SINCE INJECTION 30/9/65	DEATH	DOSE TO SKELETON (RADS)
	AGE (DAYS)	WEIGHT (KG)		D	MO YR			
F01A0.0	.	.					1383	
F02A0.0	.	.					2492	
M03A0.0	.	.					1451	
M04A0.0	.	.					3345	
M05A0.0	.	.					4713	
M06A0.0	.	.					5266	
M07A0.0	.	.					3896	
M08A0.0	.	.					3746	
F09A0.0	.	.					3719	
F10A0.0	.	.					2605	
F11A0.0	.	.					4198	
F12A0.0	.	.					4219	
F13A0.0	.	.					4527	
F14A0.0	.	.					3777	
F15A0.0	.	.					4874	
F16A0.0	.	.					4415	
F17A0.0	.	.					2145	
F19A0.0	.	.					4166	
F20A0.0	.	.					2464	
F22A0.0	.	.					4350	
M23A0.0	.	.					1741	
M24A0.0	.	.					3074	
M26A0.0	.	.					4133	
M27A0.0	.	.					2130	
M28A0.0	.	.					3114	
F32A0.0	.	.					1990	
F33A0.0	.	.					3282	
F34A0.0	.	.					2584	
M35A0.0	.	.					529	
M36A0.0	.	.					1971	
M37A0.0	.	.					4089	
F38A0.0	.	.					3802	
M42A0.0	.	.					1265	
F43A0.0	.	.					3881	
F47A0.0	.	.					1732	
M50A0.0	.	.					2264	
F51A0.0	.	.					1089	
F52A0.0	.	.					509	
F54A0.0	.	.					3190	
M56A0.0	.	.					701	
M58A0.0	.	.					767	
M59A0.0	.	.					567	
M73A0.0	.	.					5695	

DOG NUMBER	COMMENTS ON DEAD DOGS
F01A0.0	SPECIAL STUDY
F02A0.0	SPECIAL STUDY
M03A0.0	SPECIAL STUDY
M04A0.0	NOT DETERMINED
M05A0.0	TRANSITIONAL CELL CARCINOMA, NEPHRITIS, PNEUMONIA
M06A0.0	BRAIN HEMORRHAGE
M07A0.0	LYMPHOSARCOMA
M08A0.0	PROGRESSIVE PARALYSIS, CAUSE UNKNOWN
F09A0.0	VAGINAL FIBROMA
F10A0.0	SPECIAL STUDY
F11A0.0	MAMMARY CARCINOMA
F12A0.0	SEVERE OSTEOARTHRITIS
F13A0.0	SPECIAL STUDY
F14A0.0	OBTURATING EMBOLISM OF PORTAL VEIN
F15A0.0	TRANSITIONAL CELL CARCINOMA URINARY BLADDER
F16A0.0	SPECIAL STUDY
F17A0.0	TRAUMA
F19A0.0	MAMMARY GLAND CARCINOMA
F20A0.0	SPECIAL STUDY
F22A0.0	LYMPHOSARCOMA
M23A0.0	OBTURATING PULMONARY EMBOLISM
M24A0.0	SPECIAL STUDY
M26A0.0	SEMINOMA
M27A0.0	SPECIAL STUDY
M28A0.0	SPECIAL STUDY
F32A0.0	LYMPHOSARCOMA
F33A0.0	OBTURATING PULMONARY EMBOLISM
F34A0.0	SPECIAL STUDY
M35A0.0	SPECIAL STUDY
M36A0.0	SPECIAL STUDY
M37A0.0	SPECIAL STUDY
F38A0.0	MAMMARY CARCINOMA
M42A0.0	STATUS EPILEPTICUS
F43A0.0	SPECIAL STUDY
F47A0.0	SPECIAL STUDY
M50A0.0	SPECIAL STUDY
F51A0.0	SPECIAL STUDY
F52A0.0	SPECIAL STUDY
F54A0.0	SPECIAL STUDY
M56A0.0	VOLVULUS + PERITONITIS
M58A0.0	SPECIAL STUDY
M59A0.0	SPECIAL STUDY
M73A0.0	DEGENERATION OF ADRENAL GLAND + DIABETES MELLITUS

DOG NUMBER	AT INJECTION AGE (DAYS)	WEIGHT (KG)	INJECTED (μ c/KG)	DATE INJECTED D MO YR	DAYS SINCE INJECTION 30/9/65	DEATH	DOSE TO SKELETON (RADS)
M86A0.0						499	

*Time interval shown here is the animal's age.

DOG
NUMBER

COMMENTS ON DEAD DOGS

M86A0.0 SPECIAL STUDY

AN ANALYSIS OF HEMATOLOGICAL DATA FROM BEAGLES GIVEN Ra^{226}
USING THE RANDOMIZED BLOCK ANALYSIS OF VARIANCE

Jean H. Dougherty, Peter J. Mikolaj, and Richard Maxwell*

Introduction

At present the major statistical analyses being carried out on the hematological data are the randomized block analysis of variance. As a result of a previous study(1) of data from beagles given Sr^{90} , it was decided that this type of analysis better fitted the experimental design rather than the one-way analysis of variance. Other methods of analysis will also be tried in the future in order to obtain the most meaningful data. Since Ra^{226} is the radionuclide to which the others are compared, it was decided to make the preliminary analysis on the dogs injected with radium.

Methods

A series of randomized block analyses of variance were made on the radium data at 6 month intervals from 6 months post injection through 120 months post injection. A similar type of analysis on the dose-time relationship of several hematological values was made several years ago on dogs injected with Pu^{239} , Ra^{226} , Ra^{228} and Th^{228} for 24 months post injection(2). Because the 1.7 level dogs were added later in the experiment, the analysis was performed on the 0, 1, 2, 3, 4 and 5 level dogs only. An earlier study(3) indicated that there was a time trend in several hematological values; thus we could utilize only those dogs which were entered into the experiment as a block or group.

A program was written for the IBM 7040-1401 computer system at the University of Utah Computer Center. Since covariance and non-independence between paired measurements were suspected, it was decided that the

* University of Utah Computer Center.

randomized block design would provide an efficient model for the experiment.

The mathematical model used was

$$X_{ij} = M + T + B + E$$

where X_{ij} is a measurement from the i^{th} treatment and j^{th} block, M is overall or grand mean, T is the treatment effect, B is the block effect, and E is the random error effect. The numbers M , T , B are fixed constants, and E is a normally and independently distributed random variable with mean zero and common variance σ^2 . In this experiment "block" refers to a group of dogs injected at the same time and "treatment groups" are the several dose levels used.

An important assumption for this model is that the variances of all treatment groups must be equal. This is a very critical point since one would suspect that high doses of radiation may appreciably alter variances within treatment groups.

The null hypothesis for this design states there are no differences in treatment means. This hypothesis is accepted or rejected depending on whether the calculated F-ratio for treatments is smaller or larger than the tabulated value. If the null hypothesis is rejected, we must find a way to determine where the differences are among the treatment means. Since T-tests are invalid when one has more than two groups, we decided to use a multiple range test (discussed further below).

Because of the possibility of a large amount of biological variability, it was decided to include in the program a test for homogeneity of variances. The standard test is Bartlett's(4) which compares the individual variances to the average variance. After noting that the Bartlett's approached the significant reference X^2 in the intervals immediately following injection of the radionuclide, we decided to add a second test,

Cochran's(5), which compares the largest group variance to the sum of all the group variances. Thus, we would have two methods testing whether the data met the assumptions of the randomized block analysis.

A third consideration for this analysis was the handling of missing data. If a dog was found to have a clinical illness on the day it was scheduled for testing, we felt that the hematological values would reflect clinical illness not radiation and should not be included. Thus, when the situation warranted, the card was pulled from the 6 months data. Also, a value could be missing due to the death of the dog. Because the randomized block method requires a measurement for each cell, another routine was included in the program. As mentioned in the report on the dose-time relationship(2), the missing data were estimated by the Yates(6) method. In order to reduce the possibility of error, when a value is estimated the error degrees of freedom are reduced by one. In general, this increases the denominator of the F ratio, resulting in a smaller F value. To investigate just how many values could be estimated by this method, runs were made where first all the values were known, and then measurements were removed up to 50% of the entire deck. For the most part 25% of the data could be estimated without appreciably increasing or decreasing the number of significant differences. Thus, we decided upon using 25% as the maximum number of total variates to be estimated and arbitrarily set 50% and 66-2/3%, respectively, as the block and treatment maxima. When the number to be estimated for individual block or treatment exceeded the mentioned limits, the entire group was eliminated. In passing it was noted that the group variances became more homogeneous as the number of missing values increased.

A final routine that was written into the program was the multiple range test mentioned previously. To allow for future revisions in the

analysis, the test chosen was the Duncan(7). By simply changing an information card with different table values, one could perform the 'Student-Newman-Keuls' multiple range test with different probabilities of Type I and II errors. We chose the Duncan for this series of experimental analyses because we wished to minimize the possibility of rejecting a difference that was true.

In order to obtain a better picture of the overall experiment, a second computer program has been written. This program graphs by dose level (up to four levels of a radionuclide on one graph) the monthly means for all hematological values containing three or more dogs per group. Thus, all the data available can be utilized in providing a graphic representation of the experiment.

Table I. Sample Size of Radium
Randomized Block Analyses

Months Post Injection	Total Observations	Number of Blocks	Number of Dose Levels	Observations Estimated
6	72	12	6	4
12	72	12	6	4
18	66	11	6	3
24	72	12	6	3
30	72	12	6	5
36	72	12	6	9
42	72	12	6	9
48	60	12	5	4
54	60	12	5	13
60	48	12	4	3
66	48	12	4	6
72	48	12	4	10
78	48	12	4	10
84	44	11	4	10
90	30	10	3	3
96	36	12	3	5
102	36	12	3	9
108	30	10	3	8
114	18	6	3	4
120	12	4	3	2

Results

The number of dogs at the various six monthly intervals is presented in Table I. The sample size decreases with time post injection due to the death of some of the dogs. In a few instances where a large number of values were estimated (i.e., 42 months post injection, etc.) the majority of missing values came from the highest dose level at that point, since only a few dogs at this dose level were alive at this time. The 0, 1 and 2-levels were analyzed through 120 months post injection, the 3-level through 84 months, the 4-level through 54 months and the 5-level through 42 months.

Table II. Actual Values of Lymphocytes of Dogs Injected with Ra^{226} at 6 Months Post Injection

Dose Level					
0	1	2	3	4	5
3.240	3.030	4.500	2.520	1.890	1.460
4.970	5.490	3.920	3.670	3.220	1.550
2.840	<u>4.106*</u>	<u>3.557*</u>	3.900	2.380	2.140
6.770	<u>4.010</u>	<u>3.360</u>	4.720	4.610	4.250
2.960	5.290	3.110	3.150	2.390	1.570
5.260	5.130	3.420	4.660	2.360	2.020
2.050	3.730	3.220	1.770	2.180	1.140
2.810	5.120	2.820	3.140	2.320	2.120
4.970	3.860	4.180	5.220	2.170	2.090
4.070	3.300	5.490	2.740	2.170	1.390
3.630	4.650	4.000	4.570	2.580	<u>2.224*</u>
4.450	3.920	3.470	3.970	0.670	<u>1.634*</u>

* Underlined values are those which were estimated.

Dose Level	Means	S. D.	No. Dogs Per Group
0 Lymp.	4.0016665	1.3385872	12
1 Lymp.	4.3029969	0.81337972	12
2 Lymp.	3.7539061	0.72603034	12
3 Lymp.	3.6691666	1.0351414	12
4 Lymp.	2.4116666	0.90468311	12
5 Lymp.	1.9656238	0.80146036	12

Table III. Results of Analysis on Lymphocytes of Dogs
Injected with Ra²²⁶ at 6 Months Post Injection
(Similar information is available for all analyses)

Source	df	Sum of Squares	Mean Square
Total	67	113.37933	
Treat	5	52.738335	10.547667
Block	11	23.541443	2.1401311
Error	51	37.099556	0.72744227

F-Ratio for Treatments= 14.5 (5,51)

Tabled Value of F for Treatments= 2.4000000

F-Ratio for Blocks= 2.94 (11,51) F.05 = 1.98

Bartlett's Test for Homogeneity of Variances

Corrected X²= 5.6949742 (5) .40 > P > .30

Cochran's Test for Homogeneity of Variances

S= 0.32502645 (6,12) P.05 = 0.3568

Standard Error= 0.2462 df = 51

Means Being Analyzed

5 Lymp. 1.9656238

4 Lymp. 2.4116666

3 Lymp. 3.6691666

2 Lymp. 3.7539061

0 Lymp. 4.0016665

1 Lymp. 4.3029969

5 Lymp. is NE TO 3 Lymp. 2 Lymp. 0 Lymp. 1 Lymp.

4 Lymp. is NE TO 3 Lymp. 2 Lymp. 0 Lymp. 1 Lymp.

Table II shows a typical run from the computer on the lymphocyte values at 6 months post injection starting with the individual measurements. The values that have been underlined were those which were estimated. The mean lymphocyte values, standard deviations, and numbers per group are found in the lower half of the table. The remainder of the various tests performed by the computer are seen in Table III. If the F ratio found from the analysis is larger than the reference value, the program calculates the standard error of the mean and then continues with the Duncan's multiple range test. The degrees of freedom for the standard error of the mean are the same as those used in the error portion of the analysis. Thus, when a number of values are estimated, the resulting standard error is increased and a larger difference is needed before it can be called significant.

Tables IV, V, and VI present the months post injection where there are significant differences between dose levels (at the .01 or .05 level of significance) for mean values of the total white count (WBC), polymorphonuclear leukocytes (pmns) and lymphocytes, respectively. In all cases with the exception of the pmns in 5-level dogs at 42 months there was a decrease in numbers of cells rather than an increase. The volume of packed red cells (VPRC), sedimentation rate, reticulocytes, monocytes, eosinophils, and immature pmns were also analyzed in the same way but because of lack of space were not included in the tables. The only significant change in red cells occurred in the 5-level dogs as seen by a drop in VPRC and a rise in sedimentation rate at 18 through 42 months and an increase in reticulocytes at 30 and 36 months post injection. There was a depression in monocytes and eosinophils in the 3, 4 and 5-level dogs which occurred about the same time as the decrease in pmns.

As expected, the largest number of significant differences are found

Table IV. Months Post Injection Where There are Significant Differences Between Dose Levels in WBC of Dogs Injected with Ra^{226}

Comparison	Months Post Injection					
	6	12	18	24	30	78
0 vs. 1						
0 vs. 2						
0 vs. 3	.01	.01	.01			.01
0 vs. 4	.01	.01	.01	.05	.01	---
0 vs. 5	.01	.01	.01	.01	.01	---
1 vs. 2						
1 vs. 3	.01		.01			.05
1 vs. 4	.01	.01	.01	.01	.05	---
1 vs. 5	.01	.01	.01	.01	.01	---
2 vs. 3			.01			.01
2 vs. 4	.01	.01	.01			---
2 vs. 5	.01	.01	.01	.01	.05	---
3 vs. 4	.01	.01				---
3 vs. 5	.01	.01	.01	.01		---
4 vs. 5			.01	.01		---

Table V. Months Post Injection Where There are Significant Differences Between Dose Levels in pmns of Dogs Injected with Ra²²⁶

Comparison	Months Post Injection							
	6	12	18	24	30	≈	42	≈ 66
0 vs. 1								
0 vs. 2	.01							
0 vs. 3	.01	.05	.05					.05
0 vs. 4	.01	.01	.05					---
0 vs. 5	.01	.01	.01	.01	.01		.05 ↑	---
1 vs. 2								
1 vs. 3	.05		.01					
1 vs. 4	.01	.01	.01		.05			---
1 vs. 5	.01	.01	.01	.01	.01		.05 ↑	---
2 vs. 3			.01					.05
2 vs. 4	.05	.01	.01					---
2 vs. 5	.01	.01	.01	.01			.05 ↑	---
3 vs. 4	.05	.05						---
3 vs. 5	.05	.01	.05	.01			.05 ↑	---
4 vs. 5			.05	.05			.05 ↑	---

Table VI. Months Post Injection Where There are Significant Differences Between Dose Levels in Lymphocytes of Dogs Injected with Ra²²⁶

Comparison	Months Post Injection														
	6	12	18	24	30	36	42	≈	54	≈	72	78	84	≈	99
0 vs. 1															
0 vs. 2															
0 vs. 3		.05	.05								.05	.05	.05		---
0 vs. 4	.01	.01	.01	.01	.01	.05	.05		.01		---	---	---		---
0 vs. 5	.01	.01	.01	.01	.01	.05	.01		---		---	---	---		---
1 vs. 2															.05
1 vs. 3		.05					.05				.05	.05	.05		---
1 vs. 4	.01	.01	.01	.01	.05	.05	.01		.01		---	---	---		---
1 vs. 5	.01	.01	.01	.01	.01	.05	.01		---		---	---	---		---
2 vs. 3											.05	.05			---
2 vs. 4	.01	.01	.05	.05		.05			.01		---	---	---		---
2 vs. 5	.01	.01	.01	.01	.05	.05	.01		---		---	---	---		---
3 vs. 4	.01	.01		.05		.05					---	---	---		---
3 vs. 5	.01	.01	.01	.01	.01	.05	.01		---		---	---	---		---
4 vs. 5			.05	.05			.05		---		---	---	---		---

in the early monthly periods following injection of the radionuclide. The WBC, which is made up largely of pmns, is depressed at the 3, 4 and 5-level from 6 through 18 months. This depression continues through 30 months in the 4 and 5-level dogs. There is a significant fall in pmns at the 2-level at 6 months with recovery by 12 months post injection. There is no change in any hematological values at the 1-level. The pmn depression (Table V) at the 5-level continues through 30 months and these cells exceed the normal range at 42 months (↑) when the dogs become terminal. The lymphocytes (Table VI) are affected through the 3-level but go down more slowly and stay depressed for a longer interval of time (through 84 months) after injection.

Discussion and Summary

In writing the program for the randomized block analysis of variance on the Ra^{226} data, a major problem that arose was how to deal with the missing data. The test for block significance indicated that during the periods following injection up to about 36 months there was a component of variance due to the way the animals were entered into the experiment that should be removed before testing for mean differences. For this period, then, the Yates correction provided the best method of handling the data. During this early post injection time period, there were relatively few values that were missing, and thus we felt it better to estimate the missing cell rather than eliminate the row or block containing the missing value(s). Once the high level irradiated dogs were dropped from the analysis, however, there are two choices that might be made; (1) continue with the Yates estimation, or (2) go to the single classification analysis of variance when there are missing data. We chose the former method because the randomized block analysis provides greater sensitivity in that the error mean square is partitioned into the

components of block and error rather than into one component alone. We feel that most meaningful results are obtained when the analysis is consistent over the entire period tested. Thus, we kept the randomized block procedure because it provides more sensitivity in obtaining real differences.

Although the results presented above give a general picture of the depression and recovery of blood cells following irradiation, the fact that the analyses are performed on all dose levels at 6 month intervals leaves a considerable span of time without data by this method of analysis. However, there are data available from the 3-level dogs at 3 month intervals and from 4 and 5-level dogs at monthly intervals which could be utilized for comparison to controls (0-level dogs) if we had a method for estimating the values of the 0-level dogs between the 6 month intervals when counts were actually made. One method which is being tried at the present time by computer programming is to fit a curve to the actual data by running a series of polynomial equations on each hematological trait on a dog and choosing the equation (up to a 7th degree polynomial) which best describes the data points. The missing monthly values can then be generated from the curve and inserted into the randomized block program.

References

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SOFT TISSUE RETENTION OF Sr^{90} IN THE BEAGLE

David R. Atherton and Betsy J. Stover

Abstract: The concentrations of Sr^{90} found in the liver, kidneys, and spleen of beagles, measured at various times following injection, decrease with increasing time and, after a year or so, appear to decrease at the same rate as does whole body retention. These results are compared with similar measurements made on soft tissues from beagles injected with Ra^{226} and with the calcium concentrations measured in the soft tissues of humans.

Introduction

In previous publications from this laboratory(1,2,3,4,5) various features of the studies of Sr^{90} in the beagle have been reported. In those reports it has been said that Sr^{90} deposits almost exclusively in the skeleton. The purpose of this brief report is to tabulate our findings relative to the retention of Sr^{90} by non-mineralized tissue. Due to restrictions of time available for such studies, the tissues selected for analysis were limited to the liver, kidneys, and spleen, paralleling the studies done on the soft tissue retention of Ra^{226} (6).

Materials and Methods

Sr^{90} was given to the dogs in these studies in a single I.V. injection in early adulthood as described previously(5). Weighed fractions of the tissues involved were obtained at autopsy. Sr^{90} analysis was done on the tissues as described by Atherton(7).

Results

The percent of the injected dose (corrected for physical decay) retained per gram of each of the three tissues studied is listed in Table 1. Also shown are the animal's identification number, and the interval between injection and death. The tabulation is arranged in order of increasing time interval and it is apparent that the concentration of Sr^{90} in these tissues tends to decrease with increasing time.

The concentrations in spleen and liver appear to be about the same while that of the kidney appears to be higher than either except in the case of F11S5 where the concentration in the spleen is shown to be high. It is possible that this high spleen concentration is a result of mislabeling samples rather than metabolic anomaly.

Table 1. Concentration of Sr^{90} in Liver, Kidneys, and Spleen

Dog	Interval: Injection To Death (days)	$\frac{\% \text{ of Injected Dose} \times e^{-\lambda t}}{\text{gram of tissue}} \times 10^6$		
		Liver	Kidneys	Spleen
F1S1	1	1800		1100
T14S5	9	66	190	50
T16S2	9	44	240	350
T15S5	30	12	100	56
M6S5	35	20	30	18
M2S5	255	3.6		
F1S5	960	2.7	5.6	1.6
M10S5	990	5.6	7.1	0.21
M6S5A	1021	2.1	9.6	2.4
F7S5	1129	1.1	10	2.1
M12S5	1165	0.31	2.4	1.0
F4S5	1448	0.19	2.6	0.37
F8S5	1469	1.2	7.6	1.2
F11S5	1667	0.25	0.32	6.7
M2S5A	1740	0.35	3.0	1.1
F9S5	1982	0.47		0.54
M2S4	2093	0.52	4.7	0.58
F8S4	2206	0.35	4.7	0.46
M3S5	2256	0.33	3.8	0.52
M3S4	2781	0.27	5.3	0.61
F1S4	3682	0.11	2.8	1.1

In Table 2 the contribution to whole body retention made by these three tissues is shown. Also presented is animal identification and the

time interval, as in Table 1, and the whole body retention of these animals which was measured by C. W. Mays and R. D. Lloyd of our physics group and to whom we are indebted for making their results available to us.

Table 2. Comparison of Whole Body to Soft Tissue Retention of Sr^{90}

Dog	Interval: Injection To Death (days)	$R^a_{(M)}$	$\frac{R^b_{(LKS)}}{R_{(M)}} \times 10^3$
T14S5	9	0.344	74
T16S2	9	0.380	89
T15S5	30	0.242	32
M6S5	35	0.318 ^c	27
F1S5	960	0.128 ^c	9.7
M10S5	990	0.136	18
M6S5A	1021	0.126 ^c	9.9
F7S5	1129	0.163	5.2
M12S5	1165	0.113	3.8
F4S5	1448	0.0844	2.4
F8S5	1469	0.129	6.3
F11S5	1667	0.102	2.8
M2S5A	1740	0.121	3.5
M2S4	2093	0.113	4.3
F8S4	2206	0.137	3.0
M3S5	2256	0.102	3.7
M3S4	2781	0.0712	7.3
F1S4	3682	0.0694	2.9
		Average	5.9 $\pm$ 4.3 ^d

^a $R_{(M)}$ = Measured fractional whole body retention.

^b $R_{(LKS)}$ = Measured percent retention found in the liver, kidneys and spleen.

^cWhole body retention estimated from previously published equation for Sr^{90} retention in the beagle(8).

^dMean $\pm$ 1 standard deviation of values from 960 days onward.

Discussion

As preliminary studies indicated(4) the soft tissue retention of Sr^{90} , as reflected by its retention in the liver, kidneys, and spleen, is very small, and decreases with time. Perhaps the most interesting feature of the data presented here is that the contribution these three tissues make to whole body retention seems to remain somewhat constant from sometime prior to 1000 days onward. In as much as whole body retention of Sr^{90} is essentially skeletal retention and in view of the rapid "wash out" of Sr^{90} from soft parts it appears that Sr^{90} associated with soft tissues at long times following injection is controlled by the animal's Sr^{90} reservoir (the skeleton) and diminishes as the reservoir is depleted.

For comparative purposes data relative to the soft tissue retention of Ra^{226} , previously presented(6), has been treated the same as that seen in Table 2 and is shown in Table 3. Here too it appears that, from 500 days following injection and onward, the radium found in the liver, kidneys, and spleen make a rather constant contribution to that retained by the whole body. However the contribution to whole body retention made by these three tissues is about a factor of 9 higher in the case of radium than in the case of strontium, $0.052 \pm 0.034\%$ for radium and $0.0059 \pm 0.0043\%$ for strontium.

If, as seems likely, the soft tissue retention of these two alkaline earth elements, at long times following their injection, is a reflection of bone metabolism, it would be interesting to compare these findings to calcium found in the same soft tissues. Unfortunately calcium measurements on other than mineralized tissue have not been made on the animals in these studies. However the ICRP Task Group on the Revision of the Standard Man(9) has collected a great deal of data including the

Table 3. Comparison of Whole Body to Soft Tissue Retention of Ra^{226}

Dog	Interval: Injection To Death (days)	$R^a_{(M)}$	$R^b_{(LKS)} \times 10^3$
			$R_{(M)}$
M10R1.7	590	0.22	42
M10R5	825	0.21	52
M1R5	908	0.24	37
F8R5	968	0.22	73
F6R5	1015	0.30	130
T1R5	1074	0.13	42
M5R5	1220	0.23	8
M7R5	1288	0.18	51
F9R5	1288	0.24	14
F8R5	1324	0.20	140
T2R5	1368	0.12	33
M2R5	1380	0.19	53
F9R4	1470	0.16	34
M4R4	1518	0.13 ^c	47
M1R4	1606	0.18	37
M7R4	1647	0.16	54
M5R4	1659	0.26	54
M2R4	1884	0.24	14
T15R4	2127	0.17	34
F9R3	2487	0.10 ^c	64
F8R3	2612	0.10 ^c	31
M5R3	2955	0.10 ^c	110
		Average	52 ± 34^d

^a $R_{(M)}$ = Measured fractional whole body retention.

^b $R_{(LKS)}$ = Measured percent retention found in the liver, kidneys and spleen.

^cWhole body retention estimated from previously published equation for Ra^{226} retention in the beagle(8).

^dMean $\pm$ standard deviation of tabulated values.

calcium concentration, which has been published(10), and the size of the three tissues of concern in the standard man. These data are summarized in Table 4 and are compared with the radium and strontium soft tissue studies on dogs in Table 5.

Table 4. Comparison of Certain Soft Tissue to Whole Body Concentrations of Calcium in the Human

	Ash % ^(a) of Wet Weight ^(d)	$\frac{\text{g Ca (a)}}{100 \text{ g Ash (d)}}$	Wet (b) Weight	g Ash Weight (calc.)	$\frac{\text{g Ca}}{\text{Organ}}$ (calc.)
Liver	1.3±0.34	0.49±0.54	1400	18.2	0.089
Kidney	1.1±0.2	0.98±0.53	290	3.2	0.031
Spleen	1.4±0.34	0.60±0.60	165	2.3	0.014
Whole Body			7×10 ⁴		~ 960 ^c

^aRef. 10.

^bRef. 9, Table 1.

^cRef. 9, Table 3.

^dMean ± 1 standard deviation are shown.

$$\frac{\text{Total Ca in liver, kidney and spleen} \times 100}{\text{Ca in whole body}} = \frac{0.134 \times 100}{960} = 0.014\%$$

Table 5. Comparison of Alkaline Earth Soft Tissue Retentions

	% in LKS/Whole Body	Relative Values
Ca (Human)	0.014	1.0
Sr ⁹⁰ (Dog)	0.0059	0.42
Ra ²²⁶ (Dog)	0.052	3.7

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DETERMINATION OF Sr^{90} IN BIOLOGICAL MATERIAL WITH
SOLVENT EXTRACTION OF Y^{90} INTO SCINTILLATOR SOLUTION

David R. Atherton

Abstract: The general method of EHPA extraction of yttrium has been adapted for the analysis of excreta, bone and soft tissue samples containing Sr^{90} . The feature of interest in the method is that the toluene used for dilution of the EHPA contains PPO and POPOP which enables one to obtain count rates following extraction of the yttrium without further manipulation of the sample. Limit of the method is probably imposed by the counting system which in this laboratory permits the detection of 16 pCi of Y^{90} with an expected error of $\pm 5\%$ using 100 minute counting times.

Introduction

Many of the important characteristics of di(2-ethylhexyl)phosphoric acid (EHPA) have been described by Peppard et al. (1,2). Petrow (3,4) has described its use in methods used for the evaluation of Ra^{228} , Th^{228} and Sr^{90} content of biological material, while Kauffman and Matuszek (5) have described a method for its use in determining the Sr^{90} content of water.

A method of determining the Sr^{90} content of dog excreta, bone and soft tissue was developed in this laboratory and is practically the same as that described by Kauffman and Matuszek (5). Basically, the procedure is to extract Y^{90} from the specimen of interest into a 1:1 dilution of EHPA in toluene which contains 2,5 diphenyloxazole (PPO) and 1,4 bis-2-(5 phenyloxazolyl) benzene (POPOP). The organic phase is transferred to a 50 ml Erlenmeyer flask and a count rate from the decay of Y^{90} is obtained by placing the flask on a photomultiplier tube which, of course, is associated with the proper electronic gear.

Because, in this system, analysis of samples of biological material present problems not encountered in the analysis of water samples, it is felt that a brief recitation of the method and a short discussion of two problems, referred to above, could be useful.

Experimental

Apparatus. A photomultiplier tube (2 or 3 inch) in a light-tight compartment large enough to accommodate a 50 ml Erlenmeyer flask. It is preferable that the volume containing the flask be shielded with about 2" of lead. The photomultiplier tube is properly connected to power supply, preamplifier, amplifier, scaler and timer.

Reagents. Nitric Acid, 30% hydrogen peroxide, hydrochloric acid, di(2-ethylhexyl)phosphoric acid (EHPA), toluene, 2,5 diphenyloxazole (PPO), 1,4 bis-2-(5 phenyloxazolyl) benzene (POPOP), and absolute alcohol.

EHPA is prepared for use by diluting with an equal volume of toluene containing 8 gm PPO per liter and 0.2 gm POPOP per liter*.

Standard scintillator fluid is prepared by adding 4 gm PPO and 0.1 gm POPOP to a liter of toluene.

Procedure. Bone and fecal samples are prepared by incineration followed by solution in HCl. Urine and soft tissue are wet ashed with heat, concentrated HNO_3 , and hydrogen peroxide, taken to dryness and put into HCl solution.

The pH of all samples is adjusted to 1.0 and 25 ml of the EHPA-scintillator solution are added to up to 100 ml of sample solution. Samples are shaken 5 minutes (the time being noted so that a correction for decay of Y^{90} may be made) and at least 15 minutes are allowed for phase separation. The aqueous phase is drawn off and may be reserved for subsequent Y^{90} extraction (or other analysis) or discarded. The organic phase is washed with 25 ml of 0.1N HCl, and, after phase separation, the aqueous phase is disposed of as the first. The organic phase

*Some EHPA requires considerable pretreatment (3) to strip impurities from it. If pretreatment is necessary it might be well to add the PPO and POPOP after that procedure.

is transferred into a 50 ml Erlenmeyer flask, the separatory funnel is rinsed with 15 ml of standard scintillator fluid and added to the sample and finally 10 ml of absolute ethyl alcohol are added. The alcohol effects clearing of the sample which, unless prolonged times are allowed for phase separations, is an emulsion of the scintillator-extraction mixture with a trace of water.

The remaining step of the procedure is the evaluation of the Y^{90} content of the sample which is done by observing the relative count rates of the sample and a standard which is prepared in the following way. A known amount of $Sr^{90}-Y^{90}$ contained in 1 ml of a 0.1N HCl solution is placed in the same kind of flask as described above for the sample. 25 ml of the EHPA-scintillator mixture, 15 ml of standard scintillator solution and 10 ml of absolute alcohol are added. After vigorous shaking for a moment a clear standard of $Sr^{90}-Y^{90}$ results. Closing the flask tightly insures a permanent standard.

Counting is done, as described by Kauffman and Matuszek (5), such that only the light flashes resulting from the β -decay of Y^{90} are detected.

Results

Typical results for three kinds of biological samples are shown in Table I. No effort has been made to test the limit of the sample size. The sample sizes tested were chosen on practical grounds--they are the sample sizes of interest.

The counting equipment consists of the bare essentials to do this kind of counting and 0.40 counts per Y^{90} disintegration are observed with a blank* count rate of 20 c/m. This places the sensitivity of the

* The blank is prepared the same as the standard except 1.0 ml 0.1N HCl is used instead of the standard Sr^{90} solution.

counting system such that, using 100 minute counting intervals, about 16 pCi of Y^{90} can be detected with an expected counting error of $\pm 5\%$.

TABLE I
Yield of Y^{90} with EHPA-Scintillator System

Material	Amount	Fractional Recovery
Bone Ash	0.392 g	0.975
Bone Ash	1.176 g	1.01
Bone Ash	1.960 g	0.980
Urine	~ 400 ml	1.04
Feces	1/10 of 4-day collection	0.978
Feces	1/10 of 4-day collection	0.950
	Average	0.989 ± 0.03

Discussion

The procedure for extracting Y^{90} and evaluating samples of biological material is quantitative, simple, and fast. There are two points of importance relative to the preparation of these materials for extraction which need mentioning.

First, the sample to be extracted must NOT be yellow. Yellow samples result from incomplete ashing and/or the presence of iron and in either case the colored material is extracted along with Y^{90} and a quenching effect in the scintillator is observed. Incomplete ashing is most often encountered when wet ashing with concentrated HNO_3 is employed. It is our experience that wet ashing can be completed somewhat more rapidly if the sample is taken to dryness in conc. HNO_3 3 or 4 times, moistened with 30% H_2O_2 and, on a hotplate, is taken to dryness repeatedly until no charring occurs on drying. The sample is then wet with conc. HCl and diluted to the desired volume with water.

If the sample contains enough iron to produce a yellow color (red blood cells, for example) the iron can be removed by extraction with 30% Aliquat 336* in toluene from 9 N HCl solution of the sample, as described by Petrow (4), followed by readjustment of volume and pH for the EHPA extraction. An alternate and simpler method is to do an EHPA extraction as described above, discarding the organic phase. In either case the sample must be stored for an appropriate period for Y^{90} growth before an extraction for the evaluation of the Sr^{90} content of the sample can be done.

Storage of samples ready for extraction is the second point referred to above. It has been the experience of this laboratory that when samples are prepared for extraction, including adjustment of pH to 1.0, that the Y^{90} is not transferred quantitatively from the storage container to the extraction funnel even though three rinses of the storage container with 0.1N HCl were included in the procedure. Storage in either glass or plastic containers resulted in the loss of 40 to 65% of the yttrium. It was also found that a single, short (10 second) rinse of the container with the EHPA-scintillator mixture would recover the adsorbed yttrium. Inasmuch as it is hardly feasible to store samples in separatory funnels, samples are prepared for extraction, stored in 8 ounce screw cap prescription bottles and, when the extraction is to be done, the EHPA-scintillator is added and shaking is done in the bottles. The emulsion is transferred to a separatory funnel; after phase separation, the bottle is rinsed into the funnel with 25 ml 0.1N HCl. The bottle is next rinsed with 15 ml of the standard scintillator fluid which is transferred to the funnel for the last step in the procedure described above.

*Methyltricaprylammonium chloride, available from General Mills Corp.

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PREPARATION OF Sr^{90} STANDARD IN PLASTIC BLOCK
FOR DENSITOMETRIC EVALUATION OF RADIOAUTOGRAMS

D. R. Atherton and W. S. S. Jee

Introduction

At the request of the Bone Group, the preparation of a standard for the evaluation of radioautograms produced by exposure of film to tissue containing Sr^{90} was undertaken.

The material specified for the standard was a block of bioplastic*. This material will set and harden when it contains a small amount of water but it is doubtful that a uniform distribution of strontium could be effected if it were introduced in an aqueous medium.

Recently, in working on the extraction of Y^{90} (1) from Sr^{90} with EHPA, di (2-ethylhexyl) phosphoric acid, it was noted that the organic (EHPA) phase contained increasing amounts of Sr^{90} as the pH of the aqueous phase exceeded pH 2. It was therefore decided to try to extract the Sr^{90} with EHPA at a fairly high pH and then add the Sr^{90} contained in the organic phase to the bioplastic. The hope, of course, was that the two organic materials would be miscible and thus produce a uniform distribution of Sr^{90} in the finished bioplastic block.

Procedure

A 1:1 mixture of EHPA and toluene was shaken with an equal volume of a saturated solution of $(\text{NH}_4)_2\text{CO}_3$. Following phase separation, which was facilitated by centrifugation, the organic phase was washed with an equal volume of water and the organic phase retained.

The desired amount of Sr^{90} in dilute nitric acid solution was taken and the pH of the solution was raised to pH 7 to 8 by dropwise addition

*Ward's Natural Science Establishment, Inc.

of 5N NaOH. The $(\text{NH}_4)_2\text{CO}_3$ -treated EHPA, described above, was added and the two solutions shaken. Following phase separation, duplicate aliquots of the organic phase were added to 1. Bioplastic and 2. a volumetric flask.

The bioplastic and EHPA were mixed well both prior to and following the addition of the catalyst used to promote the polymerization of the bioplastic. The liquid bioplastic was weighed, placed in a chamber with a somewhat reduced pressure until entrapped gas was evolved, and then placed in a drying oven at about 100°C for 60 hours. After removal from the oven the block was kept at room temperature and weighed each day for two days at which time it appeared to have attained a constant weight.

The aliquot placed in the volumetric flask was shaken with several times its volume of 6N HCl to strip the Sr^{90} from the EHPA and the volume was adjusted to the mark with 0.1 N HCl. An aliquot of the aqueous phase of this material was evaluated for its Sr^{90} content in order that the Sr^{90} concentration of the bioplastic block could be calculated.

Volume ratios used were as follows:

Sr^{90} at pH 7 to EHPA = 2:1

Sr^{90} -EHPA to bioplastic - 1:4

Results

Y^{90} was not extracted into the EHPA under these conditions, the high pH probably caused it to adsorb onto the surface of the container.

Sr^{90} appeared to have been handled quantitatively in the system.

A preliminary report by the Bone Group indicates that the distribution of the Sr^{90} in the bioplastic block is satisfactorily uniform.

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GAMMA-RAY EMITTERS IN CONCRETE

Ray D. Lloyd, Gerald B. Folland, Bruce W. Church,
and David H. Taysum

Abstract: The content of radionuclides in samples of ready-mix concrete obtained from three local suppliers was determined by gamma-ray counting. Average concentration of gamma emitters in the concrete in pCi per gram was found to be: Ra^{226} 0.7; Ra^{228} 0.6; Th^{232} 0.6; and K^{40} 7.9 (9 mg K). Retention of Rn^{222} activity in the hardened concrete was about 85% that of the Ra^{226} . The radioactivity of constituents was also measured. Concentration of gamma-ray emitters in gravel was approximately equal to that in the concrete mix, while their concentration was about 40% higher in sand and about 50% lower in cement.

Introduction

Some contribution to the gamma-ray background is made by radioactivity in construction materials. A study of the gamma-ray activity of concrete was undertaken to select materials for the erection of our new low background counting facility.

Materials and Methods

Samples were collected for evaluation in steel cans 8.2 cm diameter x 11 cm high (#2 size) from three major suppliers of ready-mix concrete in the Salt Lake area. These suppliers were A. J. Dean and Sons Ready Mix, 3041 East 3300 South; Utah Ready Mix Concrete Co., 1730 Beck Street; and Dan R. Fogle Red-E-Mix; 337 Hartwell Avenue. Enough sand, gravel, cement and actual concrete (mix) was collected so that each type of sample from each supplier filled two #2 cans. Pieces of hardened mix were collected from Dean, while wet mix was obtained from Utah and Fogle. Other samples were dry when put into the cans.

All three companies obtain their cement from two suppliers, Utah-Portland Cement Co. (from Parley's Canyon near Salt Lake City) and Ideal Cement Co. (near Morgan, Utah). Our cement samples contained only Utah-Portland except for the Utah Ready Mix Co. sample, which was half Utah-Portland and half Ideal.

Sand and gravel are obtained from company excavations along the Wasatch Front, near Salt Lake City, in shoreline deposits of ancient Lake Bonneville, which was contemporary with the Pleistocene glacial period. An attempt was made to obtain as representative a sample of sand and gravel as possible from each supplier. However, the sand and gravel deposits are not uniform throughout, and the composition of excavated material may change as different sections of the deposit are removed for use.

Counting was done with an 8 x 4 inch NaI(Tl) crystal connected to a 400 channel pulse-height analyzer. A specially constructed plastic positioner held the 2-can samples at a standard 1.5 cm distance from the crystal face. Sample and detector were enclosed by a steel chamber with 6 inch thick walls. Sixty minute counting periods were used. The cans were initially counted unsealed after the wet concrete mix had hardened, then all cans were sealed against radon leak and recounted after a three week interval to allow the Rn^{222} to build into secular equilibrium with its parent Ra^{226} .

Standards in glass ampoules (10 ml) were counted in #2 cans containing an absorber similar in density to each type of sample. A well in the center of the absorber was provided for the ampoule. The relative counting rates of an ampoule source centered in a can and an equal activity distributed throughout a can at this distance from our crystal was determined. Glass ampoules containing $Zr^{95} + Nb^{95}$ (γ -ray energy 0.76 Mev) and K^{40} (1.46 Mev) were counted in the center well of a unit density absorber in a #2 can. Their contents were then dissolved in individual #2 cans of water and recounted. The ratio $\left[\frac{\text{cpm as ampoule in well}}{\text{cpm as distributed source}} \right]$ for the moderate energy $Zr^{95} + Nb^{95}$ was 0.906 and for the high energy K^{40} was 0.915, averaging 0.91. It was

therefore assumed that this ratio is relatively independent of the photon energies considered and this ratio was used to correct the counting rates of all ampoule sources used as standards.

Results and Discussion

Table I summarizes the results of this study. Gamma-ray emitters which were identified in each of the samples were Ra^{226} (via Bi^{214} at 1.76 Mev), Ra^{228} (via Ac^{228} at 0.93 Mev), Th^{228} (via Tl^{208} at 2.62 Mev) and K^{40} (1.46 Mev). In each energy band, the contribution of other emitters was stripped out. Concentration of these emitters in the concrete samples (in pCi/kg) averaged; Ra^{226} 738; Ra^{228} 618; Th^{228} 555; and K^{40} 7929 (9.35 gm K). Individual values were all within about $\pm 20\%$ of the averages. Unsealed concrete samples retained about 85% of the Rn^{222} being produced by the radioactive decay of Ra^{226} . Average concentration of these gamma ray emitters in the gravel samples was roughly equal to that in the mix, while the concentration in sand was about 40% higher, and in cement it was about 50% lower.

TABLE I
Concentration of Gamma-ray Emitters
in Concrete and its Constituents

Sample	Weight kg	gm K kg	pCi Ra ²²⁸ kg	pCi Th ²³² kg	pCi Ra ²²⁶ kg	$\frac{Rn^{222}}{Ra^{226}}$ in Concrete
<u>MIX</u>						
Dean	0.890	10.88	678	636	930	0.73
Utah	2.670	7.82	565	491	609	0.96
Fogle	2.726	<u>9.36</u>	<u>610</u>	<u>538</u>	<u>674</u>	<u>0.87</u>
	Average	9.35	618	555	738	0.85
<u>SAND</u>						
Dean	1.538	13.40	700	734	895	
Utah	1.938	11.88	664	683	842	
Fogle	1.344	<u>20.56</u>	<u>1018</u>	<u>1018</u>	<u>1298</u>	
	Average	15.28	794	812	1012	
<u>CEMENT</u>						
Dean	1.334	3.08	292	237	439	
Utah	1.292	4.10	334	366	597	
Fogle	1.287	<u>2.49</u>	<u>294</u>	<u>262</u>	<u>504</u>	
	Average	3.22	307	288	513	
<u>GRAVEL</u>						
Dean	1.544	12.50	553	567	844	
Utah	1.546	13.46	783	752	857	
Fogle	1.600	<u>8.05</u>	<u>326</u>	<u>339</u>	<u>500</u>	
	Average	11.34	554	553	734	

USE OF THE CHINCHILLA
IN THE STUDY OF BONE SEEKING RADIONUCLIDES

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Abstract: A brief evaluation of the suitability of the chinchilla as an experimental animal for toxicity studies dealing with several bone-seeking radionuclides is being made. This species has a maximum life span of 20 to 30 years, an epiphyseal closure time of 800 to 1000 days, and a skeletal to body weight ratio of approximately .07. The injected LD₅₀₋₃₀ dose for Ra²²⁶, given in isotonic saline via a single subcutaneous injection is about 800 μ Ci Ra²²⁶/kg.

A survey concerning the suitability of the chinchilla (Chinchilla langigera) for use in the study of some of the bone-seeking radionuclides is being made. This paper will present a few of the features that have been investigated thus far.

Three of the factors that prompted our interest in this species were the relatively long life expectancy, as indicated by some reports(1), its desirable husbandry factors, and the economy of its maintenance.

Some disagreement was found relative to longevity and to more definitely establish this parameter we mailed questionnaires to 30 recognized chinchilla ranchers in various parts of the U. S. and in Canada and England. Each was asked to indicate(1) the oldest chinchilla he had ever owned; (2) the oldest he had ever heard of; and (3) to estimate the average life span. The last item, average life span, proved to be an impractical question since such a high percentage are eventually pelted and not allowed to die a natural death. Replies to the other two questions ranged as follows:

Oldest owned: 7 to 21 years

Oldest heard of: 12 to 27 years

These data substantiate the relatively long life span and indicate the maximum to be in excess of 20 years and comparable to the dog. Thus this species could be used in some instances to compare rodent and canine

studies without life expectancy as a variable.

Another factor investigated was the closure time of the epiphyses. This was estimated by radiographic examination of partially defleshed carcasses ranging from 6 months to 5 years at the time of death and from histologic study of the proximal tibial and the distal ulnar and radial epiphyses. Based on these findings closure occurs in the appendicular skeleton between 800-1000 days - significantly later than in the dog. The skeleton of this species further differed from the dog by the absence of typical osteones.

Thus far, organ weights have been determined in only one animal. These are summarized in Table 1. A point of interest is the relatively large adrenal gland as reported in other studies(2). In determining the skeletal weight, the carcass was kept moist with isotonic saline during defleshing and was weighed in a damp condition. The marrow was not removed.

Table 1. Organ and Skeletal Weights.
(total body weight 518.35 gms; 17 months age)

	(gms)		(gms)
Heart	1.795	Testes (both)	4.851
Lungs	2.333	Adrenals (both)	0.105
Liver	16.233	Pituitary	0.010
Spleen	0.682	Eyes (both)	1.867
Kidneys (both)	4.332	Thymus	0.642
Brain	4.799	Skeleton	37.330
<hr/>			
$\frac{\text{Weight of skeleton}}{\text{Total body weight}} = \frac{37.330}{518.35} = .072$			

Ra²²⁶ toxicity studies using 20 chinchillas are in progress (Table 2). The dose levels have been arranged to elicit both acute and chronic injury, and a wide age span has been employed to observe the significance

Table 2. Summary of Chinchillas Used in Ra²²⁶ Toxicity Study

~ Injected* (μ c/kg)	Days Age at Injection	Grams Weight At Injection	Days Post Injection at Death	Days Post Injection of Survivors 15 Oct. '65
2530	349	481	17	
	495	428	21	
832	308	393	48	
	512	494	20	
276	104	336		58
	320	458	19**	
	366	326		58
	491	490		58
	760	393		149
	about 1400	648		58
77.2	104	294		58
	287	360		106
	345	436		149
	499	466		106
	583	384		106
	744	392		149
	1891	408		106
	about 5000	506		106
0.260	499	480		106
	588	506		106

* Given in isotonic saline via a single subcutaneous injection.

** The immediate cause of death was not radiation induced.

of age at injection. Administration of the nuclide was via a single subcutaneous injection in an isotonic saline solution. Early observations have indicated that the LD_{50-30} is approximately 800 injected $\mu\text{c}/\text{kg}$ of body weight (see Mays et al., this report for retention(3)).

Of the long term effects, osteosarcoma induction time should be especially interesting. If the latent period is related to life span, as suggested by Brues(4), this interval should be similar for a corresponding radiation exposure for both the dog and chinchilla.

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RADIUM RETENTION IN CHINCHILLAS

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Lynn Brewster and David R. Atherton

Abstract: Preliminary results suggest that the early retention of radium in the chinchilla is similar to that in man. This similarity, combined with the chinchilla's long life span and small space requirements may make it an excellent animal for internal emitter RBE studies. Additional work is needed and is in progress.

PILOT STUDY

A limited number of chinchillas were obtained from local breeders. Most of these animals were fur chewers and thus could be obtained at negligible cost. Ra^{226} was injected subcutaneously in the back. Unfortunately, the first group was injected with radium in sodium-citrate, citric-acid solution (pH 3.5 and 0.08 molar in total citrate). This caused a high local retention of radium in soft tissue at the injection site; therefore, all animals in the first injection group were sacrificed. Subsequent groups were injected subcutaneously with radium in physiological saline solution; in which case the skeleton was the principal site of retention.

RADIUM RETENTION (total body)

Ra^{226} retention at death in several saline-injected chinchillas is shown in Fig. 1. These values supported by total body counting results for living chinchillas (not plotted) indicate that radium retention in the chinchilla is much lower than that in the dog or mouse, and in fact appears similar to that in man. Whether this similarity will persist at later times is being determined.

EXCRETION

About 94% of the excreted Ra^{226} is eliminated in the feces, and about 6% in the urine. Similar values occur in humans. The large clearance of radium by the digestive tract causes its low retention in man. The same

may be true in the chinchilla. Blood clearance is being evaluated.

RADIUM DISTRIBUTION IN TISSUE

As shown below in Table 1, subcutaneous citrate injections resulted in a large deposition of Ra^{226} at the injection sites, whereas with saline, the skeleton contained nearly all of the body burden. The exact mechanism of this large soft tissue deposition following a sodium citrate, citric acid injection is unknown.

TABLE 1. RADIUM DISTRIBUTION

Subcutaneous injection as:	CITRATE		SALINE
Days after injection:	72		48
Chinchilla number:	ClR6	ClR7	ClR9
Skeleton	38 %	37 %	97 %
Injection site	18 %	17 %	} 3 %
Other soft tissue	44 %	46 %	
Total burden	100 %	100 %	100 %

FRACTIONAL RADON RETENTION IN TISSUE

Rn/Ra ratios were evaluated for the fresh tissues of ClR9. Unfortunately, in vivo values were not obtained for ClR7 and ClR6, but can be estimated from the Rn/Ra in thawed, cut apart samples from these animals which were exposed to air several months after death. The Rn/Ra ratio in living tissue is only slightly lower than in air-equilibrated dead tissue (see ClR9 femur and tibia sample in Table 2).

In chinchilla bone, the Rn/Ra ratio is similar to that for beagle bone at the same time after radium deposition, regardless of whether the radium was injected in saline or citrate. The high Rn/Ra ratio in the pelt and injection sites is very interesting. It is also interesting that the Rn/Ra ratio in chinchilla teeth is higher than that in chinchilla

bone, since R. E. Rowland⁺ has observed similar relationships in human teeth. In contrast, the Rn/Ra ratio in the teeth of beagles injected intravenously with Ra²²⁶ in citrate as adults is only half the Rn/Ra in their bones.⁺⁺

TABLE 2. FRACTIONAL RADON RETENTION

<u>Chinchilla</u>	<u>Tissue</u>	<u>Rn/Ra Ratio</u>	
		<u>Living</u>	<u>Dead</u>
ClR9 (saline)	Total body	0.13	
	Femur + Tibia*	0.12	0.15
	Teeth	0.19	
	Pelt	0.77	
ClR7 (citrate)	Femur + Tibia**		0.21
	Injection site		0.74
ClR6 (citrate)	Femur + Tibia**		0.18
	Injection site		0.74

* Beagle Rn/Ra in bone = 0.14 at 48 days after Ra injection.

** Beagle Rn/Ra in bone = 0.15 at 72 days after Ra injection.

SUMMARY

- (1) The metabolism of radium and radon is being studied in the chinchilla.
- (2) Large soft tissue deposition of radium occurred at the injection site when given subcutaneously in citrate solution: this effect was absent with saline.
- (3) The total body retention of radium in the chinchilla is low and is similar to that in man, at least for the first 100 days after injection.
- (4) The primary route of radium excretion is fecal for the chinchilla, as it also is in man.
- (5) The Rn/Ra ratio in chinchilla bone is similar to that in other species at the same time after radium deposition.
- (6) These preliminary results suggest that the chinchilla may be an excellent animal for internal emitter RBE studies.

⁺ Radium in Human Teeth. Arch. Oral Biol. 8:12-21, 1963.

⁺⁺ Radon retention in radium-injected beagles, Rad. Res. 8:6, 480-489 (1958).

Fig. 1. Radium retention in several species. These chinchillas were injected subcutaneously with Ra^{226} in saline solution.