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PLUTONIUM AND OTHER ACTINIDE ELEMENTS IN GONADAL TISSUE OF MAN AND ANIMALS

Running title: Plutonium in Gonads

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ABSTRACT--This report summarizes available information on the gonadal content of mammalian species given various actinide elements by various routes of administration. Emphasis is placed on plutonium. Also discussed is the contemporary level of plutonium from nuclear weapons fallout in human subjects. The fraction of the administered burden of plutonium found in the gonads (FABG) of five mammalian species following intravenous injection was about 3×10^{-4} with only about a factor of 10 between the highest and lowest values to allow for differences between sexes, among species or as a function of time following injection. FABG values tend to be smaller in the female, as compared with the male, and following inhalation or subcutaneous implant. Data on the FABG for other actinides are qualitatively similar to that for plutonium. The gonadal plutonium concentrations from fallout in United States residents are about 0.5 pCi/kg, not unlike that reported for other soft tissues, except thoracic lymph nodes, and bone.

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INTRODUCTION

A recent review of biomedical research related to plutonium was conspicuous in that it contained no reference to work on possible genetic or teratogenic effects (BAIR and THOMPSON, 1974). Another recent survey of the literature on the biological effects of this important element indicated that risk to man from internally deposited plutonium involves only lung, liver and bone and some other somatic responses (THOMPSON *et al.*, 1972). However, other investigators have noted concern for possible somatic and genetic effects of plutonium localized in gonadal tissue (KREY *et al.*, 1962; ULLBERG *et al.*, 1962; MORROW *et al.*, 1967; MATSUOKA *et al.*, 1972; OVCHARENKO, 1972; TAYLOR, 1972; TAYLOR *et al.*, 1972).

STANNARD (1973), in a review of plutonium in the environment, notes the following in the concluding section of the paper under the heading of Future Portents: "While hardly to be expected from plutonium we cannot eliminate genetic changes as a possible long-term result of contamination of the biosphere with other radionuclides. Experimental work in this area is almost non-existent, in contrast to the extensive studies with external radiation."

It is known that plutonium does reach the gonadal tissue of man (LANGHAM *et al.*, 1950; KREY *et al.*, 1962; TAKIZAWA and SUGAI, 1971; DURBIN, 1972; TAKIZAWA, 1973; CAMPBELL *et al.*, 1974; TAKIZAWA *et al.*, 1974) and that it can cross the placental barrier of rats (MOSKALEV *et al.*, 1969; SIKOV and MAHLUM, 1968) and the pregnant human female (OKABAYASHI and WATANABE, 1973). It has also been suggested that all plutonium reaching the fetus is in monomeric form (HOWARD, 1969).

Few data are available on biological changes resulting from plutonium deposition in gonadal tissue or the effects of such changes. BENSTED *et al.* (1965) reported a seminoma of the testes in a rat 59 wk after an initial injection of

1 μCi ^{239}Pu/kg, followed by four doses of 0.5 μCi/kg at 14-d intervals. Experiments using both rats and mice demonstrated the response of the testes to doses of plutonium that resulted in early lethality (HELLER, 1948; FINK, 1950; KOSHURNIKOVA, 1961). Disruption of spermatogenesis was reported for rabbits given ^{239}Pu intravenously at doses of 14 or 21 μCi/kg by KOSHURNIKOVA (1961). For smaller injection levels (2 and 7 μCi/kg), the response was decreased and intermittent inhibition of spermatogenesis was observed. However, one must keep in mind that these are large doses. For comparison, seven of nine beagles injected with 2.9 μCi ^{239}Pu/kg at Utah died of osteosarcoma at an average time of 4 yr post-injection (MAYS *et al.*, 1969).

There is little information on the long-term genetic effects of damage from plutonium deposited in the ovaries, although ovarian damage has been reported in mice following injection of large doses (30 μCi/kg) of ^{239}Pu (BLOOM, 1948). Ovarian damage was seen in some but not all mice injected with 3 μCi ^{239}Pu/kg. Damaged follicles were also observed in rabbits given 14 or 21 μCi ^{239}Pu/kg by intravenous injection (KOSHURNIKOVA, 1961). For doses of 2 or 7 μCi/kg, KOSHURNIKOVA reported the lack of corpora lutea formation at 5-9 months following injection. No significant fetal mortality was observed for pregnant rats given injections of ^{239}Pu several times during gestation for doses below about 5 μCi/kg (SIKOV and MAHLUM, 1972).

TREGUBENKO (1970) studied the fate and effects of plutonium injected into pregnant rats and the effect of pregnancy occurring long after plutonium contamination. This investigator reported that up to 42% of the ^{239}Pu citrate complex injected into rats in late pregnancy was taken up by the fetuses. The uterus, fetuses and membranes accounted for about 61% of the ^{239}Pu injected into the rat during late pregnancy. Stillbirths also were reported by

TREGUBENKO (1970). These observations must be interpreted with caution, however, as the plutonium was administered by intraperitoneal injection.

To assess possible biologic damage from high LET irradiation of gonadal tissue in the absence of a meaningful biological data base, we must first obtain information on the amount and perhaps location of plutonium in these tissues and then speculate on the possible effects from information now available for other high LET radiations. The purpose of this report is to document the findings of a literature survey of the plutonium and transplutonium element content of gonads in experimental mammals and man as the first step in the sequence of events required to estimate the possible biological effects of plutonium on gonadal tissue and perhaps ultimately the associated genetic risk.

METHODS AND MATERIALS

For ease of comparison of plutonium distribution between species of widely differing body size, the gonadal plutonium content expressed as a function of the total amount administered is used whenever possible in this report. Comparisons made on this basis do contain some uncertainty, as the fraction of the body weight represented by gonads varies between sexes and among species. In some instances, the gonadal plutonium content as a fraction of the amount administered was given by the investigator but, in others, this quantity was calculated or estimated from the original data. Standard man weights as used by the INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION (ICRP) (1959) were used for the human data. Manipulation of the data from some experiments included the reconstruction of total plutonium body burdens from data in the publications by using standard beagle (CUDDIHY *et al.*, 1970) or standard man weights (ICRP, 1959).

RESULTS AND DISCUSSION

Table 1 contains data for the gonadal plutonium content of six mammalian species given plutonium by five routes of administration. Data are given for both males and females, although both sexes are not represented for each species or route of administration. In some instances, the average value for the fraction of the administered burden in the gonads (FABG) is given for a group of animals sacrificed at one time and, in other instances, the FABG represents an average value for all animals at more than one time of sacrifice. As a first approximation, the latter case does not appear to introduce a large error because of the apparently slow turnover of gonadal plutonium.

For single oral doses of plutonium citrate or nitrate in one mouse and several pigs, the FABG is of the order of 10^{-7}-10^{-6} at relatively short times after administration. For plutonium administered subcutaneously to 48 male beagles, a large difference in the FABG is apparent for the nitrate form (1.5×10^{-4}), as compared with the oxide form (7.0×10^{-7}). The FABG value of 6.1×10^{-5} for 18 beagles (JOHNSON, 1969) is particularly interesting as the plutonium used was oxidized at ambient air temperatures, whereas the oxide used by BISTLINE (1973) was high-fired. Thus, one can detect a decrease in the three FABG values for male beagles receiving plutonium by subcutaneous implants in the following order: nitrate, air-oxidized, and high-fired plutonium.

Most of the available data on the plutonium content of gonadal tissue come from experiments in which the material was injected intravenously. Table 1 contains information on five mammalian species given ^{239}Pu as citrate or nitrate. FABG values are given for times after injection covering the range 1-1506 d. The average FABG value for the 15 intravenous injection experiments in Table 1 is 3.0×10^{-4} with only a factor of 10 between the highest and lowest values to account for differences between sexes, among species or time after injection.

The FABG value for the one female human subject is slightly smaller (9.0×10^{-5}) than those for the three males (4.8×10^{-4} at 5 d, 1.2×10^{-4} at 151 d and 2.0×10^{-4} at 155 d), but little real significance can be attached to this single result.

Individual values for the female pigs and male beagles given plutonium citrate by intravenous injection are given in Table 2. The average FABG for the female pigs is lower than that for male beagles by a factor of about three, but it is not known if this is a sex or species difference.

Table 3 compares the FABG values for both female and male rabbits given plutonium nitrate by intravenous injection. Only the sex varied in this instance, and the testes contained, on the average, seven times more plutonium than did the ovaries. It should be noted that this is not on a plutonium concentration basis (activity/g of tissue) but rather on the basis of the entire plutonium content of the gonad expressed as a fraction of the amount administered.

Data given in Table 1 for plutonium administered intratracheally to dogs and miniature swine show that less of the plutonium reaches the gonads following this route of administration, as compared with intravenous injection, as one might expect. Intratracheal administration of plutonium nitrate to miniature swine results in an FABG value which is roughly comparable to that observed for mice receiving plutonium nitrate or pigs receiving plutonium citrate by oral administration.

Table 1 also gives data for the gonadal plutonium content of female mice and beagles of both sexes given plutonium by inhalation. Plutonium-238 was the isotope used in several experiments. As expected, the FABG values are smaller, on the average, than those observed following intravenous injection. All but one of the eight inhalation experiments showed FABG values which ranged between 7.0×10^{-6} and 6.0×10^{-5}. Because of the uncertainties in knowing the actual amount of plutonium inhaled by the animals and the assumption as to the weight of the gonads, it is not realistic to attempt to derive a ratio for the FABG following the intravenous and inhalation modalities of exposure. However, it appears from data in Table 1 that the FABG following inhalation is one to two orders of magnitude smaller than that observed following intravenous injection. MORROW *et al.* (1967) state that the "accretion rate" for plutonium following an acute inhalation can be approximated by a power function. Over the period of their study the plutonium content of the ovaries in μCi/g per μCi administered was found to be $a(t)=a(1)t^{0.66}$ where t is days, a(t) is ovarian retention at any time t and a(1) is the ovarian plutonium content on day one and has the value of 1.35×10^{-5} μCi/g per μCi administered.

MORROW *et al.* (1967) also found that the mean plutonium concentration of the beagle adrenal or ovary, for times greater than 100 days after inhalation, could be expressed as a linear function of the administered dose. The values given in the original publication are incorrect.

Table 1 also gives average FABG values for rabbits given plutonium nitrate by intramuscular injection. Again, the data suggest a smaller average FABG value for females than for males by about one order of magnitude. The FABG values are in the same general range as those observed for mammals following intravenous injection of soluble plutonium compounds. The individual FABG values for various times after intramuscular injection are given in Table 4.

Some data are also available on the gonadal content of plutonium following chronic oral administration. BULDAKOV *et al.* (1969) reported the gonadal plutonium content for ovaries and testes of dogs given chronic oral administration of plutonium citrate in a 1% solution of sodium citrate (pH 6.5). The animals were sacrificed periodically out to 300 d, but it is not possible to tell how many animals were used in the study. Table 5 gives these data in units of plutonium content as a fraction of the daily dose. The values for the male dogs were obtained directly from BULDAKOV *et al.* (1969), but the values for the females were derived using relative concentration data from the same reference and assuming organ weights for the dog as derived by CUDDIHY *et al.* (1970).

We have not attempted to estimate an FABG value for plutonium in human gonadal tissue because of the uncertainties in the validity of the relatively small number of measurements available (KREY *et al.*, 1962; TAKIZAWA and SUGAI, 1971; CAMPBELL *et al.*, 1974) and the amount of fallout plutonium to which man has been exposed. The data of KREY *et al.* (1962) seem particularly high, with a concentration of 3.6 pCi Pu/kg reported for human gonads measured in 1959. The gonadal concentration was 4.6 times higher than that of lung tissue, yet the plutonium concentration of the lung seemed reasonable (0.78 pCi/kg). However, it should be kept in mind that these results were based upon only several samples.

TAKIZAWA (1973) reported the information shown in Table 6 for Japanese subjects; the measurements were made between 1963 and 1970. The ^{239}Pu concentrations were highest for the skeleton (2.44 pCi/kg), followed by the gonads (1.88 pCi/kg) and then the spleen (0.44 pCi/kg). These data are confusing in several respects. For example, the ratio of gonadal plutonium (males/females) is 0.28 in 1969 but 130 for 1970. From the experimental animal data, one would expect a value greater than one for this ratio, and one would not expect a difference of almost 500 in the ratio for both years.

CAMPBELL *et al.* (1974) reported values for the gonadal plutonium concentration of 106 United States residents and other tissue plutonium concentrations for larger sample sizes. The samples were analyzed between 1959 and 1971; these data, plus others from the same report, are shown in Table 7. These gonadal plutonium concentration values were very similar to kidney, bone and liver, slightly higher than lung and slightly lower than lymph nodes. In fact, the ratios of tissue plutonium concentrations relative to gonadal tissue shown in Table 7 are, with the exception of thoracic lymph nodes, all within a factor of about two. Thus, human gonadal tissue does not show preferential concentration of fallout plutonium as compared with other soft tissues and bone.

Additional information on the gonadal concentration of actinide elements other than plutonium in rats, dogs and baboons is given in Table 8. Although these data are not as complete as those given in Table 1 for plutonium, they do suggest FABG values similar to those observed for plutonium. An average FABG value of about 2.0×10^{-4} was obtained for rats, beagles and baboons given ^{241}Am or several isotopes of curium or californium by intravenous injection. The data cover the period from 4-2127 d following injection. The FABG values tend to be lower for females as compared with males, as was the case for plutonium. We are in the process of accruing more comprehensive tabulations which will be reported in the future.

SUMMARY

This report documents values for the gonadal plutonium content of six mammalian species given plutonium by five routes of administration. In most cases, the data are presented as the fraction of the administered dose in the gonads (FABG) at the time of sacrifice or death.

For single oral doses of plutonium citrate or nitrate in two mammalian species, the FABG is of the order of 10^{-7}-10^{-6} at relatively short times following acute exposure. Some data are presented for the amount of plutonium in the gonads of dogs following continuous oral intake for 300 d.

For plutonium subcutaneously implanted in large numbers of beagles, the gonad content was a function of the form administered, with higher FABG values observed for the more soluble forms administered. FABG values ranged from 1.5 $\times 10^{-4}$ for the nitrate form to 7.0×10^{-7} for the high-fired oxide.

The average FABG for 15 experiments (5 mammalian species) was 3.0×10^{-4} with only one order of magnitude variation between the highest and lowest values to include differences between sexes, among species and for times extending to 1506 days after administration. Data for the FABG value for human subjects (2.2×10^{-4}) were about the same as the average value of 3.0×10^{-4} observed for all species reported.

FABG values obtained following subcutaneous injection or inhalation were smaller than those reported for intravenous injection. The largest errors associated with the FABG estimates are for the inhalation experiments. All except one of the eight inhalation experiments showed FABG values ranging from 7.0×10^{-6} and 6.0×10^{-5}.

Data on plutonium contamination of human gonadal tissue are reviewed. Although some unexplained anomalies occur and are discussed, the current gonadal plutonium concentration for United States residents is approximately 0.5 pCi/kg, not unlike that reported for other soft tissues and bone.

An average retention value of about 10^{-4} of the administered dose for injected plutonium in soluble form would appear to be a reasonable estimate to use for human males. For females, a comparable value would be smaller by a factor of 5 to 10 and, for practical considerations, may be taken as 10^{-5}. This smaller FABG value for females may be directly related to the smaller mass of the female gonads as compared to the male by a factor of about 10 for some species (e.g., the beagle) but less than 10 for other species (e.g., humans). For other modalities of contamination such as inhalation or wounds nvolving insoluble forms of plutonium, these values should be reduced by ne to several orders of magnitude. A similar reduction would also appear to be ustified for oral intake of plutonium.

Because of the gross qualitative similarity in the plutonium data and that vailable for other actinides, one can apply, at least on an interim basis, he estimates given above for plutonium to other transplutonium elements. In some instances, corrections may be required for the physical half-life of the isotope. This practice would apply only to gonadal content and would not necessarily be valid for subsequent assumptions as to possible biological effects.

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Table 1. Plutonium in gonadal tissue of animals

Species	Sex	No.	Form	Time	Fraction of administered burden in gonads (FABG)	Reference
Oral						
Mouse	M	1	Nitrate	26 d	4.5×10^{-7}	COLE *et al.* (1945)
Pig	F	2-3	Citrate	1 d	2.6×10^{-6}	BULDAKOV (1968)
Subcutaneous						
Beagle	M	24	Nitrate	2 wk-1 yr	1.5×10^{-4}	BISTLINE (1973)
Beagle	M	24	Oxide	2 wk-1 yr	7.0×10^{-7}	BISTLINE (1973)
Beagle	M	18	Oxide	2 wk-1 yr	6.1×10^{-5}	JOHNSON (1969)
Intravenous						
Rat	F	20	Citrate	6 d	1.7×10^{-4}	SEIDEL and VOLF (1972)
Rat	F	20	Citrate	13 d	1.6×10^{-4}	SEIDEL and VOLF (1972)
Pig	F	7	Citrate	1-640 d	1.7×10^{-4}	BULDAKOV (1968)
Miniature swine	M	3	Citrate	6-7 d	7.4×10^{-4}	BALLOU and SMITH (1960)
Beagle	M	3	Citrate	1-362 d	4.6×10^{-4}	MAYS *et al.* (1974)
St. Bernard	F	1	Citrate	1506 d	1.3×10^{-5}	MAYS *et al.* (1974)
Mouse	F	4	Citrate	3 d	8.4×10^{-4}	ROSENTHAL *et al.* (1972)
Mouse	F	4	Citrate	90 d	4.6×10^{-4}	ROSENTHAL *et al.* (1972)
Rabbit	F	4	Citrate	3 d	9.0×10^{-5}	ROSENTHAL *et al.* (1972)
Beagle	M	3	Citrate	6 d	2.0×10^{-4}	BAXTER *et al.* (1973)
Beagle	M	3	Citrate	90 d	1.9×10^{-4}	BAXTER *et al.* (1973)
Human	M	3	Citrate	5-155 d	2.7×10^{-4}	LANGHAM *et al.* (1950)
Human	F	1	Citrate	16 d	9.0×10^{-5}	LANGHAM *et al.* (1950)

Species	Sex	No.	Form	Time	Fraction of administered burden in gonads (FABG)	Reference
Intravenous (continued)						
Mouse	F	4	Nitrate	3 d	9.8×10^{-4}	ROSENTHAL *et al.* (1972)
Rabbit	F	4	Nitrate	3 d	1.8×10^{-4}	ROSENTHAL *et al.* (1972)
Beagle	M	3	Nitrate	6 d	1.6×10^{-5}	BAXTER *et al.* (1973)
Rabbit	M	?	Nitrate	1 d-5 mo	2.7×10^{-4}	KOSHURNIKOVA (1961)
Rabbit	F	5	Nitrate	1-365 d	1.3×10^{-4}	TAYLOR (1969)
Rabbit	M	7	Nitrate	1-365 d	9.5×10^{-4}	TAYLOR (1969)
Intratracheal						
Dog	F	2	Oxide	10-11 d	1.9×10^{-5}	BAIR (1958)
Miniature swine	M	2	Nitrate	25 d	5.0×10^{-7}	BUSTAD *et al.* (1962)
Inhalation						
Mouse	F	100	Oxide	5-490 d	4.3×10^{-5}	BAIR *et al.* (1961)
Beagle	F	19	Oxide	100-500 d	7.0×10^{-4}	MORROW *et al.* (1967)
Beagle	F	3	Oxide	14 d	6.0×10^{-5}	BAIR and WILLARD (1963)
Beagle	M	3	Oxide	14 d	2.0×10^{-5}	BAIR and WILLARD (1963)
Beagle	F	5	Oxide*	30-94 d	8.0×10^{-6}	BAIR (1970b)
Beagle	M	5	Oxide*	27-77 d	2.3×10^{-5}	BAIR (1970b)
Beagle	M	3	Oxide	150 d	7.0×10^{-6}	BAIR (1970b)
Beagle	F	3	Fluoride	90 d	2.0×10^{-5}	BAIR (1970a)
Intramuscular						
Rabbit	F	2	Nitrate	28-365 d	1.0×10^{-5}	TAYLOR (1969)
Rabbit	M	9	Nitrate	1-280 d	1.3×10^{-4}	TAYLOR (1969)

*Plutonium-238.

Table 2. Plutonium in gonadal tissue of pigs and beagles at various times after intravenous injection of plutonium citrate

pecies	Sex	No.	Time	Fraction of administered burden in gonads (FABG)
g*	F	1	1 d	2.7×10^{-4}
	F	¶	9 d	1.4×10^{-4}
	F	¶	640 d	1.0×10^{-4}
eagle†	M	1	1 d	7.9×10^{-4}
	M	1	134 d	3.4×10^{-4}
	M	1	362 d	2.5×10^{-4}

*See BULDAKOV (1968).

¶Uncertain, probably 1-3 pigs per sacrifice point.

†See MAYS *et al.* (1974).

Table 3. Plutonium in gonadal tissue of rabbits at various times after intravenous injection of plutonium nitrate*

Sex	No.	Time	Fraction of administered burden in gonads (FABG)
F	1	1 d	7.0×10^{-5}
F	1	8 d	3.2×10^{-4}
F	2	112 d	7.5×10^{-5}
F	1	365 d	7.0×10^{-5}
M	1	1 d	6.0×10^{-4}
M	1	8 d	2.6×10^{-3}
M	4	112 d	1.8×10^{-4}
M	1	365 d	4.0×10^{-4}

*See TAYLOR (1969).

Table 4. Plutonium in gonadal tissue of rabbits at various times after intramuscular injection of plutonium nitrate*

Sex	No.	Time	Fraction of administered burden in gonads (FABG)
F	1	28 d	1.0×10^{-5}
F	1	365 d	1.0×10^{-5}
M	1	1 d	7.0×10^{-5}
M	2	8 d	3.0×10^{-5}
M	1	35 d	1.0×10^{-5}
M	1	49 d	2.0×10^{-4}
M	1	56 d	4.0×10^{-4}
M	2	112 d	1.0×10^{-4}
M	1	280 d	6.0×10^{-5}

*See TAYLOR (1969).

Table 5. Plutonium in gonadal tissue of dogs following chronic oral administration of plutonium citrate*

Sex	No.	Time	Fraction of daily dose in gonads at given time
M	?	10 d	8.0×10^{-6}
M	?	50 d	7.0×10^{-6}
M	?	100 d	8.0×10^{-6}
M	?	300 d	5.0×10^{-5}
F	?	10 d	1.0×10^{-7}
F	?	50 d	–
F	?	100 d	1.0×10^{-7}
F	?	300 d	1.0×10^{-6}

*See BULDAKOV *et al.* (1969).

Table 6. Plutonium in human gonadal tissue in Japanese subjects[*]

Year	Age	Sex	Plutonium concentration (pCi/kg)[†]
1963	46	M	0.29
1964	57	F	0.05
1968	62	F	0.31
1969	70	F	2.36
1969	59	F	2.56
1969	54	M	0.65
1969	68	F	2.58
1969	76	M	0.75
1970	54	F	0.09
1970	62	M	11.7

[*]See TAKIZAWA (1973).

[†]Picocuries per kilogram, wet weight.

*Table 7. Organ concentrations and ratios to gonads for $^{239-240}Pu$ in nonoccupationally exposed human subjects in the United States**

	Lung	Liver	Thoracic lymph node	Kidney	Vertebrae	Gonad
Colorado						
pCi/kg	0.249	0.784	2.78	0.881	0.432	0.568
Ratio†	0.438	1.38	4.90	1.55	0.762	-
Number of samples	95	85	68	70	90	37
New York						
pCi/kg	0.160	0.676	--	-	0.568	0.432
Ratio†	0.389	1.56	--	-	1.312	-
Number of samples	60	57	--	-	57	60
New Mexico and United States						
pCi/kg	0.405	0.405	3.14	0.140	0.208	0.676
Ratio†	0.600	0.60	4.64	0.21	0.308	-
Number of samples	93	83	81	76	57	9
All the above						
pCi/kg	0.297	0.622	2.97	0.497	0.405	0.486
Ratio†	0.611	1.28	6.11	1.02	0.833	-
Number of samples	248	225	149	146	204	106

*Weighted averages for data contained in Tables I and II of CAMPBELL *et al.* (1974, p. 30). All samples were measured between 1959 and 1973.

†Ratio of activities for organ in question to gonad.

Table 8. Transplutonium elements in gonadal tissue of animals

Element	Species	Sex	No.	Form	Time	Fraction of administered burden in gonads (FABG)	Reference
<u>Subcutaneous</u>							
^{241}Am	Beagle	M	24	Oxide	2 wk-1 yr	1.8×10^{-4}	JOHNSON *et al.* (1970)
<u>Intravenous</u>							
^{241}Am	Rat	F	4-5	Citrate	6 d	9.0×10^{-5}	SEIDEL and VOLF (1972)
	Rat	F	4-5	Citrate	13 d	8.0×10^{-5}	SEIDEL and VOLF (1972)
	Rat	F	?	Citrate	30-270 d	7.0×10^{-5}	OVCHARENKO (1971)
	Baboon	F	1	Citrate	32 d	4.6×10^{-5}	ROSEN *et al.* (1972)
	Baboon	F	1	Citrate	86 d	7.3×10^{-5}	ROSEN *et al.* (1972)
	Beagle	M	1	Citrate	7 d	2.0×10^{-5}	ATHERTON and LLOYD (1972)
	Beagle	M	1	Citrate	8 d	6.0×10^{-5}	ATHERTON and LLOYD (1972)
	Beagle	F	1	Citrate	15 d	1.4×10^{-5}	MAYS *et al.* (1974)
	Beagle	M	1	Citrate	401 d	1.4×10^{-4}	MAYS *et al.* (1974)
	Beagle	M	1	Citrate	448 d	1.4×10^{-4}	MAYS *et al.* (1974)
	Beagle	M	1	Citrate	633 d	1.1×10^{-4}	MAYS *et al.* (1974)
	Beagle	M	1	Citrate	1132 d	1.6×10^{-4}	MAYS *et al.* (1974)
	Beagle	M	1	Citrate	1198 d	1.4×10^{-4}	MAYS *et al.* (1974)
	Beagle	M	1	Citrate	1300 d	9.9×10^{-5}	MAYS *et al.* (1974)
	Beagle	M	1	Citrate	1415 d	8.0×10^{-5}	MAYS *et al.* (1974)
	Beagle	M	1	Citrate	1566 d	1.1×10^{-4}	MAYS *et al.* (1974)
	Beagle	M	1	Citrate	1779 d	9.6×10^{-5}	MAYS *et al.* (1974)
	Beagle	M	1	Citrate	1917 d	1.3×10^{-4}	MAYS *et al.* (1974)

Table 8 (continued)

Element	Species	Sex	No.	Form	Time	Fraction of administered burden in gonads (FABG)	Reference
Intravenous (continued)							
^{241}Am	Beagle	M	1	Citrate	2127 d	1.7×10^{-4}	MAYS *et al.* (1974)
	Beagle	F	1	Citrate	1510 d	9.7×10^{-6}	MAYS *et al.* (1974)
	Beagle	F	1	Citrate	1847 d	1.2×10^{-5}	MAYS *et al.* (1974)
	Rat	M	3	Chloride	4 d	8.0×10^{-4}	LANGHAM and CARTER (1951)
	Rat	M	3	Chloride	16 d	4.0×10^{-4}	LANGHAM and CARTER (1951)
	Rat	M	3	Chloride	32 d	6.0×10^{-4}	LANGHAM and CARTER (1951)
	Rat	M	3	Chloride	48 d	8.0×10^{-4}	LANGHAM and CARTER (1951)
^{242}Cm	Rat	F	4-5	Citrate	6 d	1.3×10^{-4}	SEIDEL and VOLF (1972)
	Rat	F	4-5	Citrate	13 d	1.1×10^{-4}	SEIDEL and VOLF (1972)
$^{243-244}Cm$	Beagle	M	1	Citrate	6 d	1.3×10^{-4}	MAYS *et al.* (1974)
	Beagle	M	1	Citrate	13 d	1.7×10^{-4}	MAYS *et al.* (1974)
	Beagle	M	1	Citrate	20 d	1.0×10^{-4}	MAYS *et al.* (1974)
	Beagle	M	1	Citrate	87 d	9.0×10^{-5}	MAYS *et al.* (1974)
	Beagle	M	1	Citrate	384 d	1.2×10^{-4}	MAYS *et al.* (1974)
^{249}Cf	Beagle	M	1	Citrate	7 d	3.3×10^{-4}	ATHERTON and LLOYD (1972)
	Beagle	F	1	Citrate	21 d	2.0×10^{-5}	ATHERTON and LLOYD (1972)
$^{249-252}Cf$	Beagle	F	1	Citrate	13 d	5.7×10^{-5}	MAYS *et al.* (1974)
	Beagle	M	1	Citrate	36 d	1.7×10^{-4}	MAYS *et al.* (1974)
	Beagle	M	1	Citrate	500 d	1.1×10^{-4}	MAYS *et al.* (1974)

Table 8 (continued)

Element	Species	Sex	No.	Form	Time	Fraction of administered burden in gonads (FABG)	Reference
Inhalation							
^{244}Cm	Beagle	M	2	Chloride	0.1 d	1.2×10^{-4}	McCLELLAN *et al.* (1972)
	Beagle	M	2	Chloride	2 d	1.1×10^{-4}	McCLELLAN *et al.* (1972)
	Beagle	M	2	Chloride	8 d	8.7×10^{-5}	McCLELLAN *et al.* (1972)
	Beagle	M	1	Chloride	16 d	9.9×10^{-5}	McCLELLAN *et al.* (1972)
	Beagle	M	2	Chloride	64 d	5.5×10^{-5}	McCLELLAN *et al.* (1972)
	Beagle	M	1	Chloride	128 d	5.9×10^{-5}	McCLELLAN *et al.* (1972)
	Beagle	M	2	Chloride	256 d	5.0×10^{-5}	McCLELLAN *et al.* (1972)
	Beagle	M	1	Oxide	0.1 d	5.9×10^{-5}	McCLELLAN *et al.* (1972)
	Beagle	M	1	Oxide	2 d	1.1×10^{-4}	McCLELLAN *et al.* (1972)
	Beagle	M	1	Oxide	8 d	2.0×10^{-4}	McCLELLAN *et al.* (1972)
	Beagle	M	1	Oxide	16 d	1.8×10^{-4}	McCLELLAN *et al.* (1972)
	Beagle	F	1	Oxide	2 d	3.0×10^{-6}	McCLELLAN *et al.* (1972)
	Beagle	F	1	Oxide	8 d	2.0×10^{-5}	McCLELLAN *et al.* (1972)
	Beagle	F	1	Oxide	16 d	4.0×10^{-4}	McCLELLAN *et al.* (1972)

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