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PARTITIONING OF ^{238}Pu, ^{239}Pu, AND ^{241}Am IN SKELETON AND LIVER UNITED STATES TRANSURANIUM RESGISTRY AUTOPSY CASES

R. L. Kathren

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Pacific Northwest Laboratory
Richland, Washington 99352

DISCLAIMER

PARTITIONING OF ^{238}Pu, ^{239}Pu AND ^{241}Am IN SKELETON AND LIVER UNITED STATES TRANSURANIUM REGISTRY AUTOPSY CASES

R. L. Kathren[1]
Pacific Northwest Laboratory, P. O. Box 999, Richland, WA 99352 and
United States Transuranium Registry, P.O. Box 100, Richland, WA 99352

J. F. McInroy[2]
Los Alamos National Laboratory, P. O. Box 1760, Los Alamos, NM 87545

M. M. Pixley [3]
Northwest College and University Association for Science
(University of Washington), 100 Sprout Road, Richland, WA 99352

M. J. Swint
United States Transuranium Registry, P. O. Box 100, Richland, WA 99352

ABSTRACT

Samples of human liver and bone were obtained at autopsy from former actinide workers whose occupational histories were suggestive of chronic inhalation exposure, although minor skin contaminations and wounds were documented in a few individuals. At long times after intake, the mean ratio of actinide in the skeleton relative to that in the liver was 1.73 for ^{238}Pu (36 cases), 1.4 for ^{239}Pu (43 cases), and 3.14 for ^{241}Am (25 cases). The differences between these ratios were significant at the 99% confidence level and indicate that a greater fraction (76%) of the total ^{241}Am was found in the skeleton than was found for either ^{238}Pu (63%) or ^{239}Pu (53%). These data can be compared to the current ICRP models which assume that the partitioning

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[3]Current address: University of Florida, Department of Nuclear Engineering, Gainesville, FL 32611

between liver and skeleton for each of these nuclides will be equal, and hence the ratio of activity in bone to that in the liver is 1.0 immediately after intake.

INTRODUCTION

The United States Transuranium Registry (USTR) studies the distribution and concentration of the transuranic elements in humans through radiochemical analysis of autopsy tissues donated voluntarily by occupationally exposed persons (Sw86). This report describes the results of the evaluation of data from registrants with measurable concentrations of plutonium and americium who had contributed bone and liver specimens to the Registry.

Plutonium and the higher actinides are well known as bone seekers, and were identified as such by Hamilton (Ha47). Since this early pioneering report, the propensity of plutonium and americium to concentrate in the skeleton and the liver has been confirmed by numerous other studies, largely conducted using experimental animals. The current biokinetic models of the International Commission on Radiological Protection (ICRP) assume that plutonium and americium absorbed in the bloodstream will be deposited principally in the skeleton and liver: 45% in each of these organs and the remaining 10% in the rest of the body and early excreta (ICRP79). Thus, as shown in Figure 1, based on the ICRP models, the ratio of plutonium or americium in bone to that in liver is expected to be unity soon after intake, and to increase slowly with time because of a faster clearance from liver (40y) than from bone (100y). More recently, McInroy et al. (Mc85) examined a whole body and found (about 25y after intake) that the distribution of ^{241}Am varied markedly from this model with approximately 80% of the systemic ^{241}Am in the bone and only 6% in the liver.

METHODS

To evaluate the relative distribution of plutonium isotopes and ^{241}Am in skeleton and liver, cases since 1976 with the following criteria were selected:

1. Both bone and liver specimens had been collected at autopsy.
2. These tissues had detectable quantities of one or more of the following nuclides: ^{238}Pu, ^{239}Pu, ^{241}Am.

Individuals in this study typically had 20 or more years of employment at facilities where plutonium and americium were processed. For most of the cases exposure was assumed to have occurred from chronic low level inhalation over a period of several to many years, since there was no history of accidental acute inhalation, ingestion or a wound. Tissue samples were collected from USTR registrants and forwarded to Los Alamos National Laboratory for radiochemical analysis. The analytical procedures involved drying and ashing of tissues, dissolution in nitric acid and removal of an aliquot for analysis. After the addition of ^{242}Pu and ^{243}Am tracers, separation and isolation of plutonium and americium was accomplished by anion exchange and electroplating onto stainless steel disks for quantitative alpha spectrometry. The detailed radiochemical procedures have been described by Boyd, Eutsler and McInroy and by McInroy et al. (Bo81; Mc85).

Concentrations of ^{239}Pu in bone and liver were available for 43 cases (Table 1). Similar data for ^{241}Am were available for 25 cases (Table 1). The concentration data were converted to organ content by assuming the organ mass to be that given for Reference Man: 2.8 kg for bone ash and 1.8 kg wet mass for liver (ICRP75). After this conversion, the data were compared using the

content or ratio of actinide nuclide in the skeleton relative to the liver.

RESULTS AND DISCUSSION

Figures 2 through 4 are histograms indicating the number of cases and the corresponding percentage of ^{238}Pu, ^{239}Pu and ^{241}Am in bone relative to total amount in bone plus liver. Table 1 summarizes the data for each radionuclide. The ICRP models predict equal amounts of these nuclides will be deposited in the skeleton and liver from the transfer compartment (i.e. blood). In the 43 cases where data were available for ^{239}Pu, the amount in the skeleton ranged from 23% to 97% of the total in the skeleton plus liver, with a mean of 53.2% and a standard deviation of 18.2%. This mean is not significantly different from that predicted by the ICRP model, but does not support the 70:30 partitioning ratio between skeleton and liver proposed by Thomas, Healy and McInroy (Th84). In other words, the ratio of the amount in the bone to the amount in the liver was 1.14, compared with the ratios of 1.0 from the ICRP model and 2.33 from Thomas, Healy and McInroy (ICRP79; Th84).

In the 36 cases where ^{238}Pu data were available (Table 2), the amount in the skeleton ranged from 20%-99% of the total amount in both the skeleton and liver, with a mean of 63.4% and a standard deviation of 24.1%. Thus, the ratio of the amount in the bone relative to the amount in the liver was 1.73.

The difference between these means for the plutonium isotopes is significant at the 99% confidence level ($p < 0.02$), and suggests that a greater proportion of ^{238}Pu than ^{239}Pu is deposited in the skeleton. This observation is in agreement with the work of Mewhinney and Diel where enhanced dissolution, translocation, and excretion of ^{238}Pu were observed in beagle dogs exposed to $^{238}PuO_2$ aerosols compared to previous studies where animals

were exposed to $^{239}PuO_2$ (Me83). However, the observation differs from the ICRP model which predicts initially equal amounts in the skeleton and liver (ICRP79).

Data were available on ^{241}Am content in 25 cases. One of these cases was the USTR whole body previously described (Mc85). In these cases, the amount in the skeleton relative to the total in the skeleton plus liver ranged from 48% to 97%, with a mean of 75.8% and standard deviation of 15.3%. Thus, the ratio of the amount in bone relative to the amount in liver was 3.13, as compared with the 1.0 suggested by the ICRP model (ICRP79). The difference between the mean percentage of ^{241}Am in the skeleton and that of the two plutonium isotopes was significant at the 99% confidence level ($p < 0.01$), which strongly suggests that americium is lost more rapidly from liver than bone and supports the models put forth by Griffith and coworkers and more recently by Durbin and Schmidt in which the half-life for ^{241}Am in liver is about two years (Du85; GR83). It would also support a model in which a greater fraction of ^{241}Am than ^{239}Pu is deposited in the bone.

The 25 ^{241}Am cases were part of the universe of 43 ^{239}Pu cases mentioned above. Therefore, it was possible to compare the relative fractionation of ^{241}Am and ^{239}Pu between bone and liver for these 25 cases. These data are shown in Figure 5 where the percentage of ^{241}Am and ^{239}Pu in the skeleton (relative to the total in the skeleton and liver) are plotted. The data points for the ^{239}Pu and ^{241}Am tend to track together suggesting that the two nuclides are handled similarly within the body. For ^{239}Pu the mean is 53.2% with a standard deviation of 18.2% as compared with a mean of 75.8% and a standard deviation of 15.3% for ^{241}Am.

It is reasonable to assume that the plutonium and americium exposure

routes were similar in these cases. The logical conclusion appears to be that for these chronic long-term exposure cases, a smaller percentage of americium than plutonium is retained in the liver. However, the details of the exposure of these cases are not known at this time; it is likely that at least some individuals were exposed to a mixture of plutonium isotopes, including ^{241}Pu the parent of ^{241}Am. Thus, at least some of the ^{241}Am in the bone might have resulted from decay of this relatively short-lived (13-year half-life) isotope of plutonium. However, this is insufficient to explain the relatively large fraction of americium in the skeleton. Moreover, the results of the single whole body analyzed by the USTR suggest that about 80% of the systemic burden of americium was in the skeleton (Mc85). These data seem to be more consistent with a model in which the half-life of americium in the liver is relatively short, perhaps on the order of 2 years as suggested by Griffith et al. and Durbin and Schmidt and certainly less than the 40 years proposed by the ICRP (Gr83, Du85, ICRP79).

A similar examination was made of the 36 cases where both ^{238}Pu and ^{239}Pu data were available. The data points are plotted in Figure 6 and show the two plutonium isotopes tracking together, although there is a greater percentage of ^{238}Pu in the skeleton than ^{239}Pu.

CONCLUSIONS

On the basis of the partial human body cases analyzed by the USTR, it appears that, at least for chronic exposures, the partitioning of the three actinide nuclides, ^{238}Pu, ^{239}Pu and ^{241}Am between the skeleton and liver in humans is not the same. For ^{239}Pu, there was approximately equal partitioning between the skeleton and the liver; while for ^{238}Pu there was about 1.7 times

more in the skeleton as in the liver. For ^{241}Am the amount in the skeleton was about 3 times that in the liver.

This difference in partitioning is of significance in biokinetic modeling and the establishment of permissible intake limits for these nuclides. The partitioning factors observed in this report indicate that the annual limits on intake for ^{238}Pu and ^{241}Am put forth by the ICRP (ICRP79), which assumed equal partitioning between bone and liver, may be high by a factor of approximately 25% and 50%, respectively, considering only the dose to bone. However, these factors are only about 12% or 13% high based on the weighted committed dose equivalent in target organs or tissues following intake by inhalation.

ACKNOWLEDGEMENTS

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Table 1. Estimated organ burden of ^{238}Pu, ^{239}Pu and ^{241}Am at autopsy based on radiochemical analyses

Case Number	^{238}Pu (Bq)		^{239}Pu (Bq)		^{241}Am (Bq)	
	Liver	Skeleton	Liver	Skeleton	Liver	Skeleton
13	0.28	0.35	4.29	3.62	0.07	3.17
16	0.003	0.093	0.06	0.27		
18	0.44	0.81	23.5	26.7	--	--
20	0.01	0.22	0.10	0.29	0.02	0.04
21	0.08	0.11	4.51	4.67	0.34	0.81
22	0.05	0.43	2.99	2.27	--	--
58	0.07	0.10	2.04	3.47	--	--
60	0.23	0.32				
79	0.01	0.28	0.36	0.38		
82	0.007	0.353	0.05	0.15	0.17	2.98
90	0.005	0.345	0.10	0.36		
93	0.79	0.42	4.30	1.98		
94	0.05	0.54	0.10	0.28		
100	0.12	0.09	0.59	0.66	--	--
101	0.005	0.012	0.08	0.38		
102	0.03	0.77	1.37	2.29	554.0	6623.1
104	0.04	0.15	0.27	0.36	0.13	0.37
106	14.8	6.97	0.15	4.23		
107	--	--	2.04	3.46	0.20	0.99
108	4.04	1.12	145.3	54.7	9.82	21.7
141	28.2	16.4	414.8	326.7		
142	0.59	0.65	27.7	23.3	17.5	52.4
143	0.06	0.05	5.50	2.42	--	--
144	0.007	0.005	0.38	0.61	0.01	0.14
145	0.65	2.49	48.8	81.1	19.4	23.5
147			0.04	0.20	0.02	0.24
148	1.40	0.71	70.3	27.7	7.16	9.50
149	0.04	0.04	2.78	1.93	0.17	0.46
150	0.06	0.15	0.69	2.67	0.26	2.08
151	0.28	0.42	13.7	19.5	--	--
152	4.48	1.14	168.4	100.9	6.50	18.4
153	0.21	0.05	5.34	1.49	0.92	0.86
154	0.005	0.037	0.09	0.34	0.02	0.21
155	0.03	0.04	1.69	1.44	0.13	0.29
156	0.02	0.10	0.11	0.05		

Table 1. Estimated organ burden of ^{238}Pu, ^{239}Pu and ^{241}Am at autopsy based on radiochemical analyses (cont.)

Case Number	^{238}Pu (Bq)		^{239}Pu (Bq)		^{241}Am (Bq)	
	Liver	Skeleton	Liver	Skeleton	Liver	Skeleton
157			0.14	0.20	0.28	0.32
160	--	--	0.94	0.32	0.04	1.00
187	0.05	0.52	1.43	4.28	0.93	10.5
188	0.65	0.63	28.9	14.2	3.75	5.25
190	--	--	0.02	0.07	0.05	0.12
192			1.53	0.98		
193	6.33	3.53				
195			0.09	0.11	--	--
197			0.46	0.38	0.03	0.33
198			0.22	0.32		

Table 2. Summary of observations for the partitioning of ^{238}Pu, ^{239}Pu and ^{241}Am between skeleton and liver in USTR autopsy cases

	No. of Cases	$\frac{\text{Activity in skeleton}}{\text{Activity in skeleton + liver}} \times 100$	Standard Deviation	Median	Range
ICRP 30 Model (^{238}Pu, ^{239}Pu, ^{241}Am)	---	50%	---	---	---
^{238}Pu	36	63.4%	24.1	63.5%	20%-99%
^{239}Pu	43	53.2%	18.2	53%	23%-97%
^{241}Am	25	75.8%	15.3	75%	48%-98%

Figure I. Relative activity in skeleton and liver for Pu and Am calculated from ICRP 30 data.

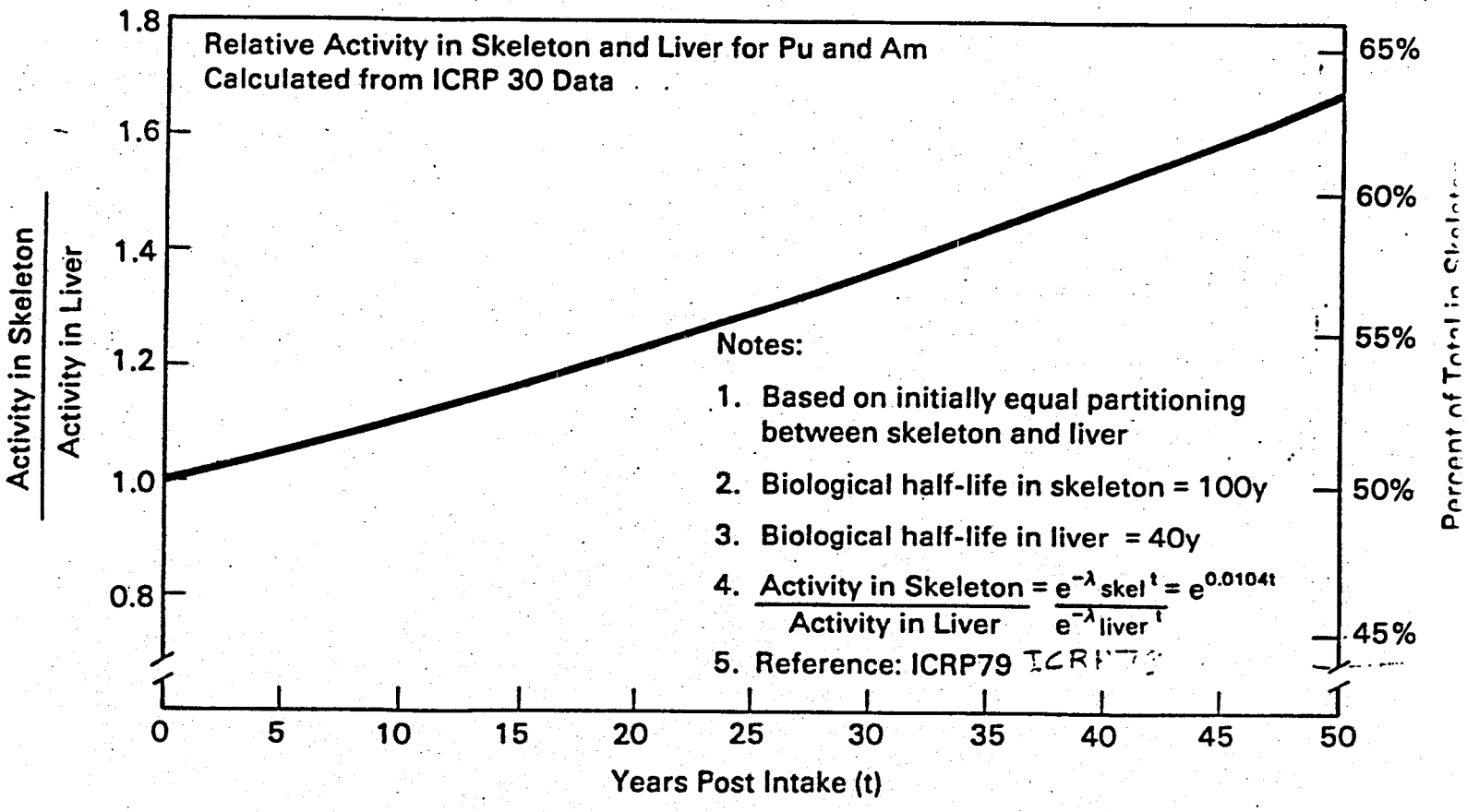


Figure 2. ^{238}Pu case distribution

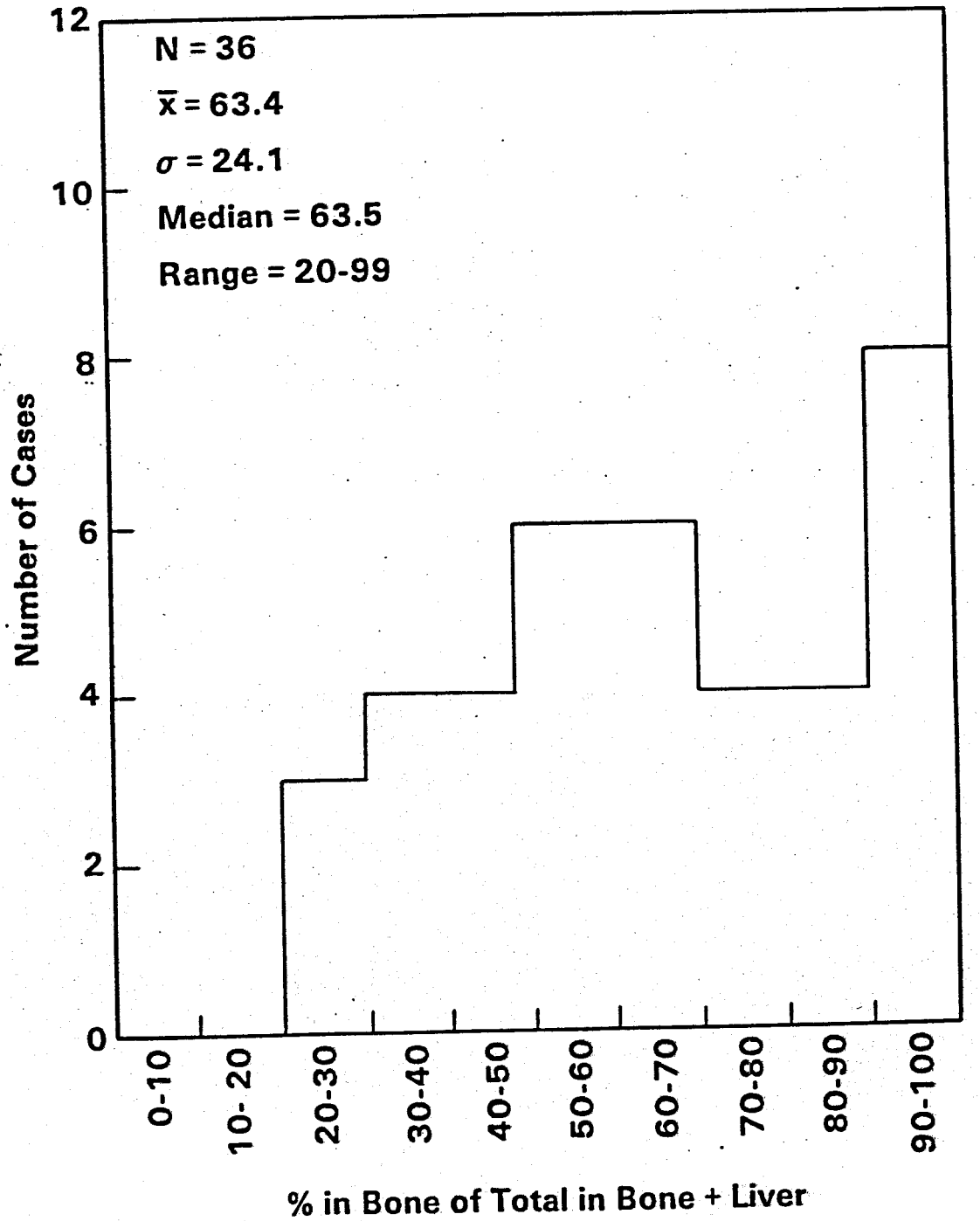


Figure 3. ^{239}Pu case distribution

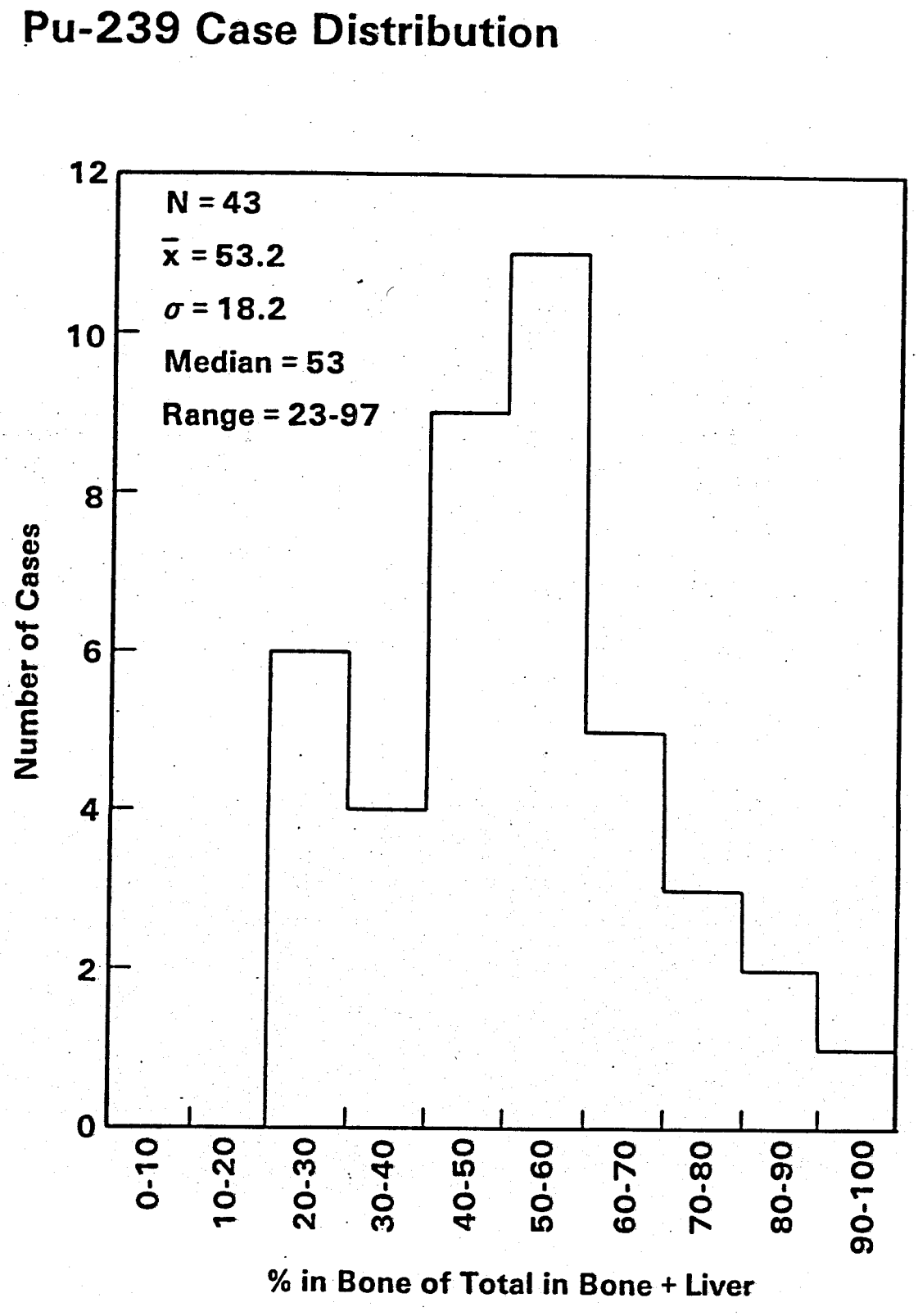
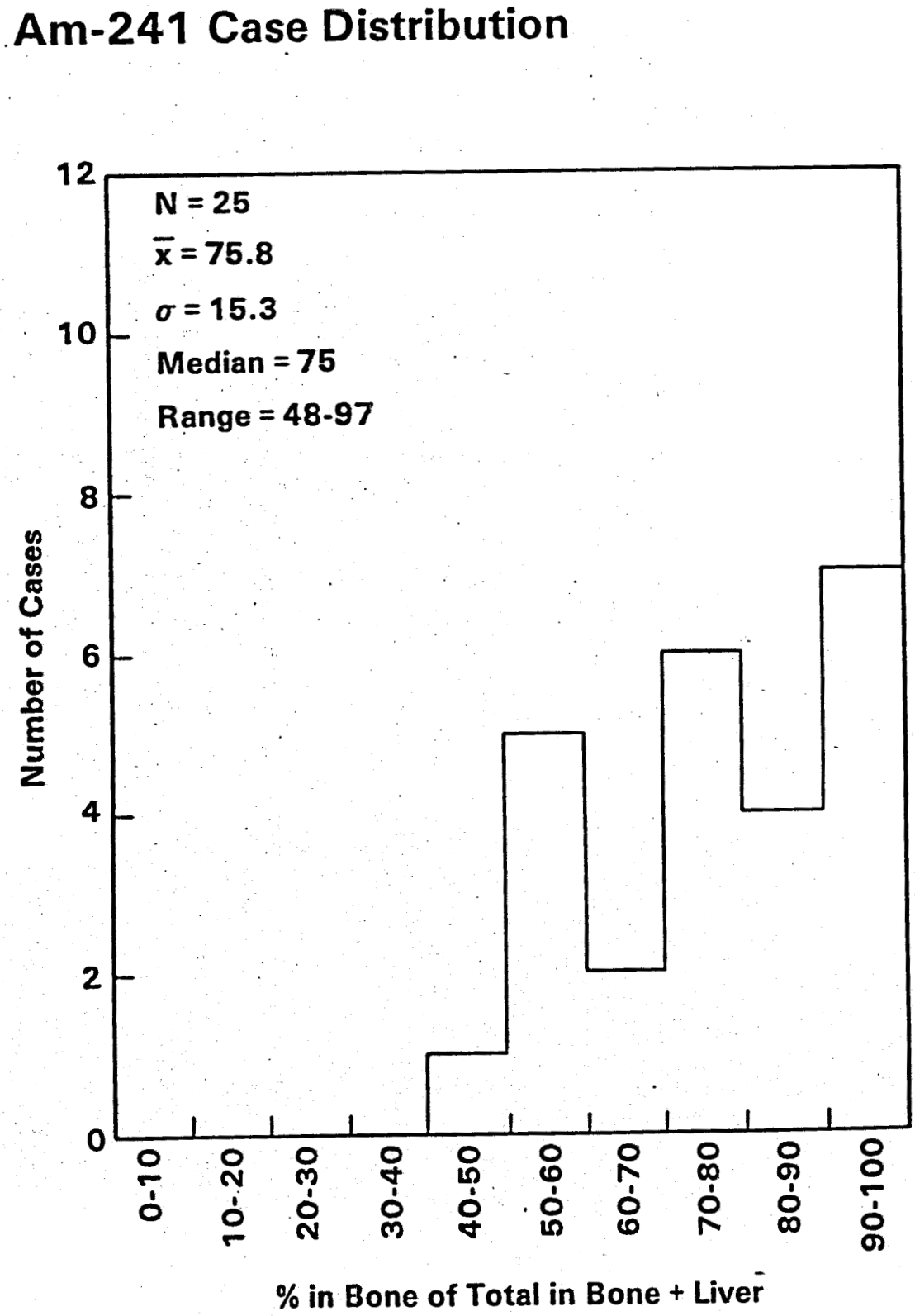


Figure 4. ^{241}Am case distribution



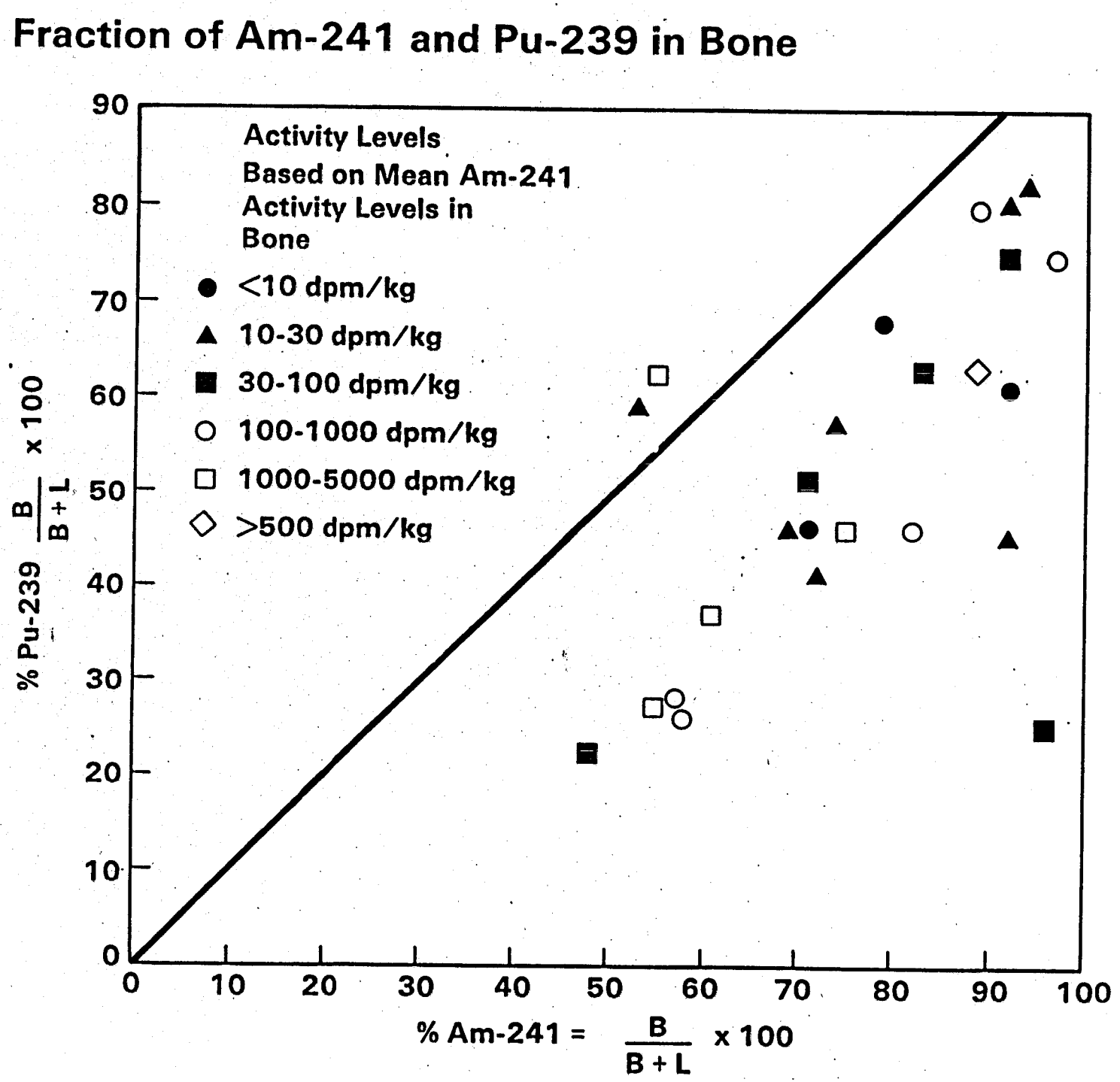


Figure 5. Fraction of ^{241}Am and ^{239}Pu in bone.

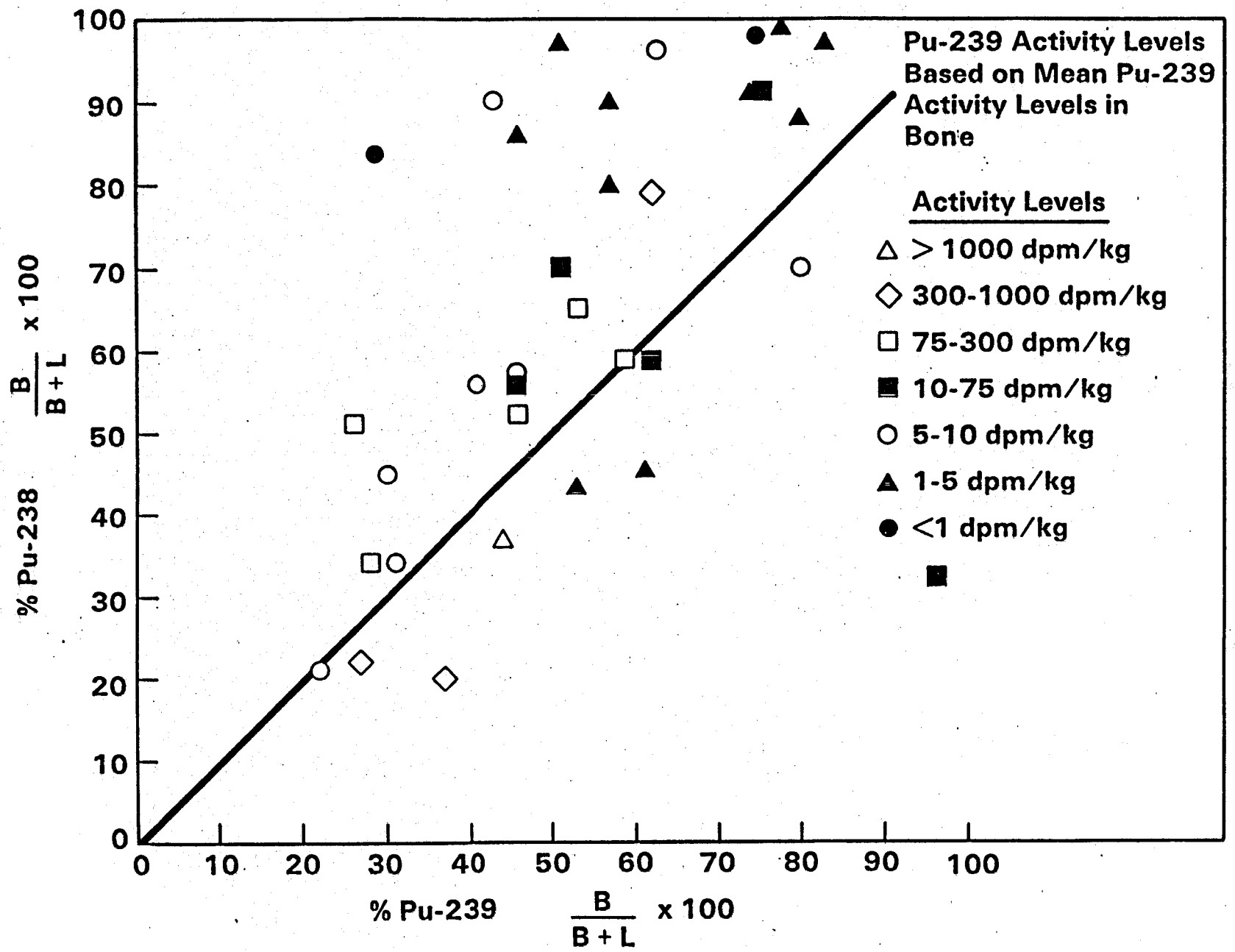


Figure 6. Fraction of ^{238}Pu and ^{239}Pu in skeleton.