

Report on Naturally Occurring  
Radionuclides in Human Tissues

by

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## Remarks

The present report was prepared to update the former report on naturally occurring radionuclides in human tissues (A/AC 82/G/L.1045) with the addition of newly acquired information and to include some old data which was taken from the 1962 UNSCEAR report for the purpose of comparison. However, only limited data was included here from these old publications because of the following reasons.

Some data is concerned with only total alpha activity. Other with nuclide content in whole body ash. And, some data on nuclide content in bone ash is included again in more recent reports by the same authors.

The information in high natural radiation areas is still scanty because of the difficulty of sampling human tissues in such areas. Several old figures on Ra<sup>226</sup> in the bones of inhabitants in Kerala, India, showed a much higher value than in normal bones. But there is little data available. (table 1)

The recent data on samples of teeth collected in the Araxá and Tapira region of Brazil, where high radioactive intrusives are found, revealed a tendency toward a higher content of Ra<sup>226</sup> than in other regions. (table 1) Further, the teeth of two Indian tribes in Brazil that eat Brazil nuts, were found to show a several times higher content of Ra<sup>226</sup> than in those of the inhabitants of New Jersey which were analyzed at the same time. (table 2)

Pb<sup>210</sup> levels in bones of Canadian Eskimos who had been permanent residents in the Arctic were found to be considerably higher than the levels in bones of Canadian Eskimos who had been residing in southern Canada for some time prior to removal of the bone. (table 4) This high value is probably due to the special food-chain of lichen-reindeer-Eskimos. The same phenomenon was also found for soft tissues as the result of high Po<sup>210</sup> content in placenta of Canadian Arctic Eskimos. (table 7)

Attention has been paid recently to the effect of cigarette smoking on the Po<sup>210</sup> content in human tissues. It was found through research on various parts of lung tissue of smokers that there is a considerably higher level of Po<sup>210</sup> content than in those of non-smokers. (table 7)

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Table 1. <sup>226</sup>Ra in human bone

LOCALITY	NUMBER OF SAMPLE	pCi/g (10 <sup>-3</sup> ) fresh weight	pCi/g (10 <sup>-2</sup> ) ash	pCi/g (10 <sup>-2</sup> ) Ca	Sample type	Reference
U.S.A. (mostly Illinois)	128		3.7 (0.5 - 28.6)		rib, skull, tibia, vertebrae femur, etc.	(3)
U.S.A. (Chicago residents last 15 yrs. or more)	14		1.5 (0.5 - 2.8)		rib	(3)
U.S.A. New York	64			3.2	vertebrae	(1)
San Francisco	71			2.6	"	
U.S.A. (Rochester)	9	3.4 ± 0.4 (1.8 - 4.8)			clavicle	(5)
		1.1 ± 0.3 (0.36 - 2.9)			vertebrae	
U.S.A.	42		1.2 (0.5 - 2.7)		rib	(22)

foot note:

(1) ± SE.

(2) figures in brackets indicate the range (Min. - Max.)

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$^{226}\text{Ra}$  in human bone (continued)

Locality	Number of sample	pCi/g( $10^{-3}$ ) fresh weight	pCi/g( $10^{-2}$ ) ash	pCi/g( $10^{-2}$ ) Ca	Sample type	Reference
U.S.A. (New York City)	140		0.8		total skeleton	(23)
U.S.A. (Wisconsin)	1 1		2.9 1.5		total skeleton	(14)
Puerto Rico (San Juan)	27			1.7	vertebrae	(2)
U.S.A. (New England)			1.4			(26)
U.S.A. (Illinois)	32		2.8 (0.2 - 7.5)			(27)

<sup>226</sup>Ra in human bone (continued)

LOCALITY	NUMBER OF SAMPLE	pCi/g (10 <sup>-3</sup> ) fresh weight	pCi/g (10 <sup>-2</sup> ) ash	pCi/g (10 <sup>-2</sup> ) Ca	Sample type	Reference
U.K.	1		0.8	2	femur	(8)
	1		0.8	2		
	1		2.0	5		
Germany	22	3.9	1.46		femur	(10)
		(1.8 - 7.8)	(0.7 - 2.9)		tibia	
Germany	25	3.8 ± 1.2	1.4 ± 0.4		femur	(11)
Germany	47	1.30 ± 0.90 (0.10 - 4.77)	1.30 ± 0.60 (0.39 - 3.16)	4.0 ± 2.0 (1.1 - 9.5)	foetal bone, 4-10 months	(12)
Germany	1	5.4	1.2	3	tibia (composite sample of 56 individuals)	(24)
	1	4.8	1.1	5	femur (" 37 individuals)	
Japan	12		0.4 (0.0 - 1.0)		rib, etc.	(21)
age (7-19)						
	27		1.4 (0.2 - 4.8)			
age (20-70)						

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<sup>226</sup>Ra in human bone (continued)

Locality	Number of samples	pCi/g(10 <sup>-3</sup> ) fresh weight	pCi/g(10 <sup>-2</sup> ) ash	pCi/g(10 <sup>-2</sup> ) Ca	Sample type	Reference
Canada (Vancouver)	7		0.6		single	
Chile (Santiago)	3		3.0		bone ash	(23)
Switzerland (Zurich)	1		1.6			
U.S.A. (Denver)	1		1.1			
Venezuela (Caracas)	4		0.3			
Germany (Koln & Bonn)	5		2.0			
Various countries	15		1.2 (0.4 - 3.6)		composite bone ash	(23)
India (Kerala)	1		7.6		cortical bone	(18)
	1		10.5			
	1		12.7			

Table 2 <sup>226</sup>Ra in human teeth

Locality	Number of sample	pCi/g(10 <sup>-2</sup> ) ash	pCi/g(10 <sup>-2</sup> ) Ca	Reference
U.S.A.	25	1.4		
(northern	15	2.0		
New England)	20	0.9		
	20	1.0		(16)
	20	1.8		
	20	1.6		
	20	1.4		
	20	2.5		
U.S.A.	1 (0 - 10 yrs)		7.8	
(New Jersey)	1 (10 - 20 yrs)		1.2	
each sample includes	1 (20 - 30 yrs)		0.6	(19)
20 - 40 teeth	1 (30 - 40 yrs)		3.8	
	1 (40 - 50 yrs)		1.7	
	average		3.0	

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<sup>226</sup>Ra in human teeth (continued)

Locality	Number of sample	pCi/g(10 <sup>2</sup> ) ash	pCi/g(10 <sup>-2</sup> ) la	Reference
Brazil				
Indian, Caiabis	1		14	
Indian, Canecoiro	1		27	(19)
(Brazil nut eater)	average		21	
Brazil				
Guarapari	23	3.6 ± 2.3 (0.6-10.4)		
Meaipe	15	2.3 ± 1.9 (0.6-7.7)		
Vitoria	14	3.0 ± 2.2 (0.8-7.9)		
Rio de Janeiro	13	3.7 ± 2.9 (0.6-12.3)		(17)
Poços de Caldas	13	1.5 ± 0.8 (0.6-3.1)		and
Araxa	24	8.0 ± 5.0 (0.8-20.4)		(20)
Tapira	12	6.0 ± 4.2 (1.8-16.0)		
Ax. and Tp. (high activity area only)	16	8.5 ± 4.8 (2.1-18.8)		

Table 3.  $^{228}\text{Ra}$  or  $^{228}\text{Th}$  in human bone

Locality	Number of sample	pCi/g( $10^{-3}$ ) fresh weight	pCi/g( $10^{-2}$ ) ash	pCi/g( $10^{-2}$ ) Ca	Sample type	Reference
Germany (Th)	25	$1.4 \pm 0.5$	$0.5 \pm 0.2$		femur	(11)
U.K. (Ra)	1 1 1			1 1 2	femur	(8)
India (Th) Kerala	1 1 1		2.8 1.1 1.1		cortical bone	(18)
U.S.A. (Ra)	32		0.7 (0.2 - 1.9)			(27)

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Table 4.  $^{210}\text{Pb}$  (RaD) or  $^{210}\text{Po}$  (RaF) in human bone

Locality	Number of sample	pCi/g( $10^{-2}$ ) fresh weight	pCi/g( $10^{-2}$ ) ash	Sample type	Reference
U.S.A. (mostly Illinois)	128		14.6 (3.7 - 45.4)	rib, skull, tibia, vertebrae, femur, etc.	(3)
			trabecular (67)* 18.4		
			male (47)* 19.6		
			female (20)* 15.6		
			Cortical (61)* 10.5		
			male (36)* 11.5		
			female (25)* 9.0		
U.S.A. (Chicago residents last 15 yrs. or more)	14		17.7 (6.3 - 35.5)	rib	(3)
U.S.A.	5	(Po) 1.8 (1.2 - 2.7)		lower thoracic vertebrae	(15)
U.S.A. (Illinois)	32		8.0 (1.9 - 18.2)		(27)
U.S.A. (New England)	25		14.2		(26)

Foot note: (1) \* number of samples

(2) data are  $^{210}\text{Pb}$  unless otherwise indicated

Table 4.  $^{210}\text{Pb}$  (RaD) or  $^{210}\text{Po}$  (RaF) in human bone (continued)

Locality	Number of sample	pCi/g( $10^{-2}$ ) fresh weight	pCi/g( $10^{-2}$ ) ash	Sample type	Reference
Puerto Rico (Caribbean Island)	28		11.8 (4.9 - 23.7)	vertebrae	(4)
			male (19) 13.3 (6.4-23.7) female (9) 8.8 (4.9-12.6)		
Poland (Warsaw)	20	4.05 (1.52 - 5.9)		vertebrae	(6)
Germany	20	(Pb) $3.2 \pm 1.7$ (Po) $3.1 \pm 1.0$	$11 \pm 4$ $13 \pm 5$	femur tibia	(11)
U.K.	9	(Po) 1.7		vertebrae	(7)

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$^{210}\text{Pb}(\text{RaD})$  or  $^{210}\text{Po}(\text{RaF})$  in human bone (continued)

Locality	Number of Sample	pCi/g( $10^{-2}$ ) fresh weight	pCi/g( $10^{-2}$ ) ash	Sample type	Reference
U.K.	6	2.6 (2.1 - 3.4)		5 vertebrae 1 tibia	(25)
Canada (Eskimos)					
Igloolik, NW Territory		71			
unknown		38			
Carberry, Man.		0.8			
Winnipeg, Man.		1.3			
Edmonton, Alta.		2.7			
unknown		1.2			(13)
Pakatawagan, Man.		3.7			
Nelson House, Man.		4.2			
Nelson House, Man.		4.0			
unknown		10			

Table 5 <sup>210</sup>Po in human teeth

Locality	Number of Sample	pCi/g (10 <sup>-2</sup> ) ash	Reference
U.S.A.	25	5.0	
(Northern New England)	15	5.7	
	20	5.2	
	20	4.7	
	20	5.6	(16)
	20	6.1	
	20	5.0	
	20	5.9	

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Table 6. <sup>226</sup>Ra in human soft tissues

Locality	Tissue	Number of sample	pCi/g(10 <sup>-4</sup> ) fresh weight	pCi/g(10 <sup>-2</sup> ) ash	pCi/g Ca	Reference
Germany	kidney	3	1.0	1.0	0.50	
	testicles	3	0.9	0.9	0.46	
	spleen	3	1.0	0.9	0.98	
	intestine	3	1.0	2.2	0.83	
	liver	3	1.6	1.3	1.60	(12)
	muscle	3	0.5	0.5	0.48	
	pancreas	3	0.7	1.2	0.38	
	average		0.9	1.1	0.75	
Germany	fetal soft tissue (4-10 months)	15	1.1 (0.5-1.9)	1.2 (0.6-2.3)	0.70 (0.31-1.49)	(12)
	Placenta	9	1.6 (0.7-3.1)	1.4 (0.7-2.4)	0.35 (0.21-0.56)	
U.S.A. (Rochester)	liver	9	1.8 ± 1.0			
	skeletal muscle	11	0.5 ± 0.2			(5)
	spleen	9	1.0 ± 0.4			
	kidney	11	1.2 ± 0.3			
	heart	9	0.7 ± 0.2			

PLEASE NOTE

- 13a -

The column at the bottom of page 13 ( $\text{Po}^{210}$  in placenta) is replaced by the following table.

Locality		No. of sample	pc/g( $10^{-3}$ ) fresh weight	Reference
Canada	Judson's Bay Coast (a)	6	114	
	" (b)	7	115	
"	inland, rural (a)	2	34.1	
	" (b)	4	14.4	(28)
"	Yellowknife, N.W.T (a)	1	24.1	
	" (b)	1	3.5	
	" (c)	11	3.6	
U.K.	London (c)	10	3.3	

Diet Class (a) much reindeer and caribou  
(b) some " "  
(c) normal diet

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Table 7. <sup>210</sup>Po in human soft tissues

Locality	Tissues	Number of sample	pCi/g(10 <sup>-3</sup> ) fresh weight	Reference
U. K.	liver	4	10	(7)
	kidney	2	7.1	
	spleen	3	3.2	
	lung	2	3.0	
	skelotal muscle	5	1.1	
	testis	4	3.3	
Germany	liver	3	13	(9)
	spleen	3	3	
	muscle	3	2	
	kidney	3	5	
U. S. A.	liver	4	11	(3)
	muscle	2	6	
Canadian Arctic	placenta	9	59.0	(28)
Southern Canada	"	9	5.0	
United Kingdom	"	10	3.3	

$^{210}\text{Po}$  in human soft tissues (continued)

Locality	Tissues	Number of sample	pCi/g( $10^{-3}$ ) fresh weight	Reference
U. K. (cigarette smoker & non-smoker)	liver	4 (6)	20 (14.8)	(13)
	branch. tree	4 (6)	7.3 (3.1)	
	alveolae	4 (6)	9.9 (3.4)	
	mean lung	4 (6)	8.6 (3.2)	
	kidney	4 (5)	20.5 (15)	
	gonad	4 (2)	3.9 (2.8)	

figures without brackets are for cigarette smokers and those in brackets are for non-smokers

210 Po in human soft tissues (continued)

Locality	Tissue	Number of sample	pCi/g ( $10^{-3}$ ) fresh weight	Reference	
U.S.A.	Peribronchial lymph node (smokers + non-smokers)	17	11 (6-20)		
	lung parenchyma	(smokers)	12	8 (2-20)	
		(non-smokers)	5	1.8 (1-2)	
	smokers {	( major bronchi	12	28	(15)
		( segmental bronchi	12	53	
		( upper lobe			
		( segmental bifurcations	12	189	
	smokers {	( lower lobe			
		( segmental bifurcations	12	318	
		renal cortex	5	(3 smokers + 2 non-smokers) 12 (8-20)	
		liver	5	( " ) 12 (8-21)	
		spleen	5	( " ) 2 (1-3)	
	urinary bladder	5	( " ) 1 (0.5-2)		

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### Common Strontium Content of the Human Skeleton

The geochemical and biogeochemical behavior of the element strontium is important in understanding the movement of fission-product strontium-90 into man (1). Several investigators (2, 3) have analyzed human bone from different locations for strontium. The availability of a large collection of bones from the study of world-wide fallout of strontium-90 made convenient the examination of this parameter in greater detail. This report (4) is concerned with (i) the distribution of strontium among the different bone in an individual skeleton, (ii) the distribution of strontium in the population of a single city, and (iii) the extension of information on geographical variation. Samples consisted of a variety of bones from eleven individuals, whole skeleton ash from 133 New York City caavers, and composites from 16 localities, each representing equal weights of the ash from 4 to 38 individuals.

The analyses were performed by an emission spectrographic technique modified from that of Turekian and Kulp (2). The standard used to define the working curves were actual samples of bone ash which were analyzed by the isotope dilution method (accurate to within 5 percent). All samples were run in duplicate and are reported as parts of strontium per million. The reproducibility of these analyses is estimated to be about  $\pm 10$  percent.

The average strontium content of additional samples from previously investigated areas (2) was found to be about 30 percent lower. In order to check this discrepancy, some of the original samples were reanalyzed by the present method. The new analyses were also about 30 percent lower in each case. Synthetic standards similar to those used by Turekian and Kulp (2) were analyzed, using the present working curve defined by isotope dilution analyses of bone ash. The results indicate that a matrix difference between bone and chemically precipitated phosphate is responsible for the higher values reported in the earlier work (2). In view of this observation, the samples of Turekian and Kulp were reanalyzed by the present method and redetermined.

The distribution of common strontium among the different bones of individuals was examined by analyzing the femur, tibia, fibula, humerus, ulna, radius, hand or foot bones, skull, pelvis-sternum, vertebrae, ribs, clavicle, scapula, and kneecap from eleven skeletons (5). Although the average strontium content of the whole skeleton varied by a factor of 3 among these individuals, there was no systematic difference in strontium content between any two bones of the body outside of the experimental error (standard deviation of 10 percent).

Thus a single bone can give a valid estimate of the common strontium content of the body at this level of certainty. This would also be the case for strontium-90 distribution if a population ingested a diet with a constant Sr<sup>90</sup>/Ca ratio throughout the lifetime of the individuals.

The histogram (Fig. 1) of the strontium concentration in 133 individuals (whole skeleton ash) from New York City shows a nearly normal distribution with a standard deviation that is only about  $\pm 32$  percent of the mean of 162 parts per million by weight. The narrow spread reflects the averaging of food sources in a city environment.

The data on the concentration of strontium in human bone in various geographical localities are summarized in Table 1. To show that the use of composite samples is valid, the samples from Boston and Tokyo were run individually, and then equal weights of bone ash were combined into composite samples. There appear to be small but significant differences from one locality to the next. The average for any given locality falls within a factor of 2 of the mean of the data (172 ppm). Recent work by Sowden and Stinch (6) on a limited number of samples from England analyzed by neutron activation gives results which are consistent within the experimental and natural variation of those reported here. Their work shows a lower strontium concentration in young children. This is expected as a result of fetal discrimination against strontium (7). An examination of the present analyses shows that for adults there is no age effect.

The average world-wide value of  $(\%Sr)/(\%Ca) \times 10^3$  in human bone derived from Table 1 is  $0.45 \pm 0.1$ . The value  $(\%Sr/\%Ca) \times 10^3$  in average rock or soil is  $7 \pm 1$  (8). The discrimination factor between soil and skeleton for the strontium/calcium ratio is therefore  $15 \pm 2$ . The experimentally determined discrimination factor for strontium/calcium between soil and plant is about unity (9), between plant and milk, about 7 (10), and between milk or vegetation and human bone it is about 4 (1). Thus, if in the average urban world population, half of the calcium in the diet comes from milk, and half from

Table 1. World survey of common strontium in human bone.

Location	No. of samples	Sr in bone ash	
		ppm	Av
<i>North America</i>			
Boston	37	101	
Boston	38	109	105
Boston	62*	117	
New York	134*	162	162
Houston	14†	125	
Houston	12	190	152
Denver	33†	203	203
Vancouver	17†	164	
Vancouver	12	117	144
San Juan	5†	179	179
Guatemala	29	156	156
<i>South America</i>			
Recife	6†	344	344
Guayaquil	17	179	179
Cordoba	18	160	160
Santiago	37†	160	160
Santiago	24	160	
Caracas	37†	187	187
<i>Europe</i>			
West Germany	30†	137	137
Copenhagen	2†	242	
Copenhagen	4	256	253
Zurich	1†	140	140
Rome	9†	160	
Rome	10	258	206
London	4†	187	
London	21	156	160
<i>Asia</i>			
Tokyo	36	206	
Tokyo	21*	199	206
Tokyo	5†	203	
Taiwan	19†	191	
Taiwan	6	179	187
India	30†	176	
India	12	214	187
<i>Africa</i>			
Durban	13	195	195
Liberia	1	324	324
World av			172

\* Samples run individually. † Samples reported by Turekian and Kulp (2) run as composites.

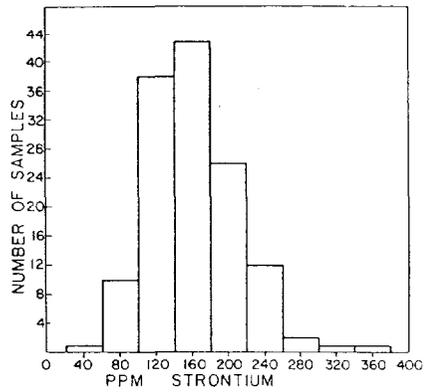


Fig. 1. Histogram of common strontium in ash of whole skeleton from New York City.

vegetables, the predicted over-all discrimination factor would be 16. This

figure is in good agreement with the geochemical value of  $15 \pm 2$ . If strontium-90 becomes uniformly mixed with the soil, as may occur in tilled fields, this factor will permit prediction of human bone level directly from soil analyses.

The relatively uniform distribution of common strontium in human bone reflects the uniformity in human diet. This observation means that variations in strontium/calcium ratios in different areas will not be an important factor in the distribution of strontium-90 from nuclear tests in the world's population.

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