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RADIOLOGICAL AND ENVIRONMENTAL RESEARCH DIVISION ANNUAL REPORT

Center for Human Radiobiology

July 1977—June 1978

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ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

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FOREWORD

The first paper in this Annual Report describes five recently discovered cases of malignancy attributed to radium in patients with measured body burdens of radium. Included is a case of bone sarcoma diagnosed in 1977, the second since the Center was established in 1969. During the same period, seven cases of carcinoma of the mastoid air cells were diagnosed. The great importance of malignant tumors of head sinuses as a manifestation of radium toxicity is indicated by publication of a comprehensive review of these cases (cf. paper 2) and study of the tissues at risk (paper 9). At the same time, new data are being obtained on cells possibly at risk for induction of osteosarcoma (paper 5). In an analysis of dose-response relationships (paper 3), only the contribution from ^{226}Ra and its daughters was included in the dose for head carcinomas, whereas dose contributions from both ^{226}Ra and ^{228}Ra were included for bone sarcomas. For other reports from the Center on the possible health effects of radium, the reader is referred to papers 4 and 8 and to the list of publications at the back of this Report.

Among new results in the study of persons injected with plutonium in the 1940s, it is of interest to note that measurable amounts of plutonium were found in the hair of a woman who died 1.4 years after injection and that the lengthwise distribution may reflect the relative concentration in the blood as a function of time (paper 20). Paper 27 is a report on the radioactivity content of plants and animals sampled in the vicinity of tailings piles from uranium mills; this is part of a cooperative study with Argonne's Division of Environmental Impact Studies.

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THE PLUTONIUM INJECTION CASES: AN UPDATE TO 1977*

R. E. Rowland and Patricia W. Durbin†

Several hospitalized individuals of relatively short life expectancy were given intravenous injections of plutonium in 1945–1947, and excreta were collected and measured for as long as they remained hospitalized.[1] Following the discovery by Durbin[2] that some of these individuals were still living, she and, subsequently, the Center for Human Radiobiology at the Argonne National Laboratory made an effort to trace all of these unique cases. This search resulted in a published report which documented the doses of plutonium administered, the survival of the recipients, the causes of death, and the doses accumulated by liver and bone in each case.[3]

The injections of plutonium contained from about two to more than 100 times the maximum permissible body burden of 40 nCi; two contained ^{238}Pu, while the remainder contained only ^{239}Pu. Seven of those injected succumbed to their illness within one year after receiving plutonium. Three more died in less than two and a half years. The remaining eight cases survived at least eight years, and four were still alive in 1975 when the Rowland and Durbin report was prepared.

The surviving cases are of considerable interest, for each carries a high level of plutonium in their liver and skeleton. One case died in November of 1975, identified as HP-8, of causes that do not seem to be related to injected plutonium. Three remain alive at this time, having carried plutonium for more than 30 years. Two are considered to have body burdens about seven times the maximum permissible level.

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*Summary of an oral presentation at the Scientific Group Meeting on Long-Term Effects of Radium and Thorium in Man, Geneva, 12–16 September 1977 (World Health Organization).

†Lawrence Berkeley Laboratory, Berkeley, California 94720.

Table 1 updates the calculated average organ doses accumulated by the members of this group to death or to 31 July 1977. Table 2 lists the causes of death, contributory causes, and durations of illnesses, as determined from death certificates. As far as we can determine, the internally deposited plutonium was not responsible for or related to the death of any of these cases.

Table 1. Calculated bone and liver doses

Case	Injection, μCi		Dates		Survival, days	Calculated α-ray doses, rads	
	^{238}Pu	^{239}Pu	Injection	Death		Bone	Liver
Cal-I	3.5	0.046	5/14/45	1/9/66	7545	580	1460
Cal-II	-	0.169	4/26/46	1/6/47	255	2.5	8.7
Cal-III	0.095	-	7/18/47	Living	10971[a]	11	27
Chi-I	-	0.40	4/26/45	10/3/45	160	1.5	4.2
Chi-II	-	5.9	12/27/45	1/13/46	17	3.5	8.5
Chi-III	-	5.9	12/27/45	Unknown	~ 170	24	70
HP-1	-	0.28	10/16/45	1/12/60	5201	33	85
HP-2	-	0.31	10/23/45	4/4/48	894	6.5	18
HP-3	-	0.30	11/27/45	Living	11569[a]	110	230
HP-4	-	0.30	11/27/45	4/29/47	518	5.4	13
HP-5	-	0.31	11/30/45	4/29/46	150	1.1	3.1
HP-6	-	0.33	2/1/46	Living	11503[a]	81	190
HP-7	-	0.39	2/8/46	10/27/46	261	3.5	8.6
HP-8	-	0.40	3/9/46	11/22/75	10850	140	290
HP-9	-	0.39	4/3/46	7/2/47	455	4.2	12
HP-10	-	0.38	7/16/46	6/2/57	3974	34	91
HP-11	-	0.40	2/20/46	2/26/46	6	0.06	0.16
HP-12	-	0.29	4/10/45	4/13/53	2925	20	52

[a]To 31 July 1977

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Table 2. Causes of death as given on death certificates

Case	Sex	Date of birth	Age at injection	Age at death	Cause of death Contributory causes
Cal-I	M	10/11/86	58	79	Cardio-respiratory failure (12 hr) Pulmonary edema (2 day); arteriosclerotic heart disease with decompensation (1 wk)
Cal-II	M	5/26/41	4	5	Sarcoma of knee (9 mo)[a]
Cal-III	M	1/26/11	36	--	(Living)
Chi-I	M	3/20/77	68	68	Recurrence of cancer of chin and metastasis to lungs (1 yr)[a]
Chi-II	F	1/25/89	56	56	Metastatic carcinoma of aberrant breast tissue (5 mo)[a]
Chi-III	M	Unknown	Unknown	Unknown	(Lost to study after ~ 170 day)
HP-1	M	5/20/78	67	81	Bronchopneumonia (3 day) General arteriosclerosis (unknown interval)
HP-2	M	8/5/97	48	50	Hypertensive encephyalopathy (days) ? Cerebral hemorrhage (days); hypertensive cardiovascular disease (years);[a] hemophilia (years)[a]
HP-3	F	4/1/97	48	--	(Living)
HP-4	F	2/9/27	18	20	Cushing syndrome (6 yr)[a] Adenoma-pituitary (6 yr)
HP-5	M	1/4/89	56	57	Bronchopneumonia (2 day) Amyotrophic lateral sclerosis (2 yr, 6 mo)[a]
HP-6	M	11/14/01	44	--	(Living)
HP-7	F	5/7/86	59	60	Pulmonary failure Pneumonia; left base rheumatic heart; thyrotoxic goiter
HP-8	F	9/9/04	41	71	Malnutrition and electrolyte imbalance (several weeks) Carcinoma of larynx (2 yr); scleroderma; arteriosclerotic heart disease
HP-9	M	8/18/81	64	65	Terminal bronchopneumonia (days) Laryngeal edema and debilitation (days); dermatomyositis (years)[a]
HP-10	M	10/31/93	52	63	Arteriosclerotic heart disease[a]
HP-11	M	1/29/77	69	69	Bronchopneumonia (days) Cirrhosis of liver (years); congestion of viscera (days); arteriosclerosis (years)
HP-12	M	3/17/90	55	63	Heart failure (3 wk) Auricular fibrillation (3 wk)

[a]Diagnosed illness at time of injection.

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3. R. E. Rowland and P. W. Durbin, Survival, Causes of Death, and Estimated Tissue Doses in a Group of Human Being Injected with Plutonium, The Health Effects of Plutonium and Radium, J. W. Press, Salt Lake City, pp. 329–341 (1976).

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BLOOD CONTENT AND EXCRETORY PLASMA CLEARANCE OF PLUTONIUM 10^4 DAYS AFTER INJECTION*

J. Rundo and F. H. Ilcewicz†

Blood samples were taken from two subjects who had been injected intravenously with about 0.3 μCi ^{239}Pu(IV) as the citrate 10^4 days previously; the subjects were on a metabolic ward, and all urine and feces were collected. Plutonium was determined by alpha-spectrometric isotope dilution in the samples of excreta[1,2] and in separated plasma and red cells.[3] The concentration of ^{239}Pu in the plasma of each subject was four or five times that in the red cells; the ^{239}Pu in the latter was thought to be due to entrained plasma.

By dividing the daily excretion rate (urinary or urinary plus fecal) by the contemporary concentration in the plasma, we obtain the urinary or total excretory plasma clearance. The results summarized in Table 1 show that while the excretion rate is higher for the female than for the male, the reverse is true for the plasma clearance.

Concentrations of ^{239}Pu in excreta and in whole blood shortly after the injections were reported by Langham et al.[4] In order to calculate the excretory clearance at early times for comparison with our results, we had to make certain assumptions about the hematocrit and the density of plasma.[3] With these assumptions we obtained the results plotted in Figures 1 and 2. For both subjects our results are very similar to those at two or three days after injection, including the higher value for the male. The difference between the excretion rates of the two subjects may be a consequence of the higher degree of osteoporosis to be expected in a female although case 40-009 did not have clinical osteoporosis. However, this would not explain the lower excretory plasma clearance.

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*Summary of paper presented at 22nd Annual Meeting of the Health Physics Society, Atlanta, Georgia, July 4–8, 1977.

†Deceased.

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Table 1. Excretion rates and plasma clearance of ^{239}Pu 10^4 days after intravenous injection in two subjects.

Case number (sex)	40-009 (F)	40-012 (M)
Urinary excretion, pCi/day[a]	7.60 ± 0.21	4.68 ± 0.17
Fecal excretion, pCi/day[a]	3.17 ± 0.09	1.77 ± 0.01
Plasma concentration, pCi/L	97 ± 5	39 ± 2
Urinary plasma clearance, L/day[c]	0.078 ± 0.004	0.12 ± 0.01
Total excretory plasma clearance, L/day[c]	0.111 ± 0.006	0.17 ± 0.01

[a] 1 pCi/d = 37 mBq/d

[b] 1 pCi/L = 37 Bq/m^3

[c] 1 L/d = 0.001 m^3/d

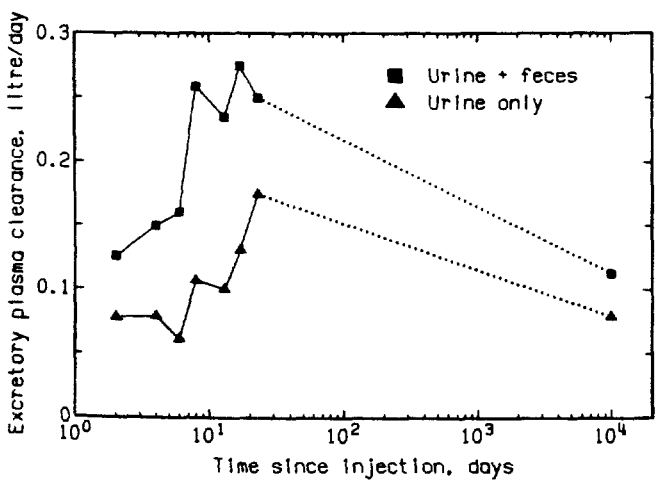

FIG. 1.--Excretory plasma clearance as a function of time on a logarithmic scale for case 40-009, a female, age 49 years at the time of the injection and 77 years 10^4 days later.

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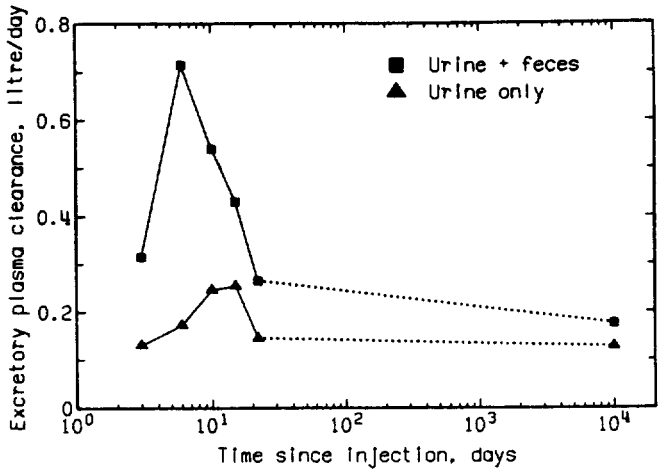

FIG. 2.--As for Figure 1, but for case 40-012, a male, age 45 years at the time of the injection and 73 years 10^4 days later.

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DISTRIBUTION OF INJECTED PLUTONIUM IN THE SKELETON AND CERTAIN SOFT TISSUES

R. P. Larsen, R. D. Oldham, C. G. Cacic,* J. E. Farnham, and J. R. Schneider*

The burden and macrodistribution of plutonium in the skeleton and its concentration in certain soft tissues have been determined in the remains of a woman who received plutonium by injection. The method of analysis was alpha spectrometric-isotopic dilution. The skeletal burden was 54 ± 2% of the amount injected. As expected, the concentrations in bones that are primarily trabecular were much higher than those that are primarily cortical: The ratio of the concentration in the bodies of the thoracic vertebrae to that in the diaphysis of the tibia was 40. The bones of the skull and the clavicle are quite representative of the entire skeleton. The concentrations in soft tissue are a factor of about 100 lower than those in bone. The concentration in hair increases markedly with the distance from the scalp.

The burden and macrodistribution of plutonium in the skeletal remains of a woman who in 1945 received 11 kBq (0.3 μCi) of plutonium-239 by injection have been determined. At the time of injection she was suffering from Cushing's syndrome, hypertension, nephropathy with uremia, and osteoporosis; she succumbed to her illnesses in 1947 at age 20. The plutonium she received was tetravalent and in a citrate buffer medium. The subject, referred to in the early literature as HP-4,[1] has been assigned CHR case number 40-010. Preliminary results obtained by using both a xenon-filled proportional counter and radiochemical methods to determine plutonium in a few bones, as well as its distribution in a long bone, the tibia, were reported previously.[2,3]

The remains at the time of exhumation were in excellent condition, considering the 26 years of interment. There was no evidence of severe decay. The skin was dehydrated, shriveled, and discolored, but the flesh was moist. Examination showed that a complete autopsy had been performed and all organs as well as the brain had been removed.

*Participant in the Undergraduate Research Program, Center for Educational Affairs.

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Sampling

Prior to dissection various tissue samples were taken: diaphragm, thigh muscle (quadriceps femoris) and skin, nerves (femoral), costal cartilage, trachea with larynx, scalp with hair, eyes, and teeth. At dissection the flesh was carefully removed from the bones, leaving as much as possible of the periosteum intact.

With the exception of the tibia, the samples of bone analyzed were from the left half of the skeleton. For the paired bones there were three types of samples: (1) groups of bones, such as the tarsals, (2) individual bones, such as the scapula, and (3) sections of individual bones, such as the tibia. The unpaired bones were cut in half, and there were two types of samples from these halves: (1) groups of sectioned bones, such as the processes of the cervical vertebrae and (2) individual bones, such as the sacrum. In the sampling of the skull, the paranasal and mastoid sinuses were removed, and the remainder of the skull was cut in half along the mid-saggital plane and segmented. The samples from the skull were (1) half the frontal bone and a large fraction of the left parietal bone, (2) the remainder of this parietal bone and half the occipital bone, (3) the left temporal squamous bone, and (4) half the mandible. The samples from the paranasal and mastoid sinuses were not analyzed.

Analytical Methodology

The method of analysis was alpha spectrometric-isotope dilution. The bone was ashed at 600°C, weighed, and a weight aliquot taken. This was dissolved in nitric acid, a known amount of ^{242}Pu and an excess of 9M hydrobromic acid were added and the solution was evaporated to incipient dryness. This insured isotopic exchange between the ^{239}Pu that was in the bone and the isotopic diluent, ^{242}Pu. The plutonium was separated from the other bone constituents, using the anion exchange procedure of Larsen and Oldham;[4] it was electrodeposited, using the technique reported by Kressin;[5] and the deposit was assayed in an alpha spectrometer. The plutonium recovery ranged from 75 to 90%; the resolution (FWHM) of the ^{239}Pu and ^{242}Pu peaks in

the spectra ranged from 10 to 13 fJ. The precision and accuracy of the values obtained are limited by the statistics of counting the ^{239}Pu. As a quality control procedure, one bone sample was analyzed repeatedly (10 times) during the period the determinations were made, and 25 other bone samples were analyzed in duplicate at separate times. The agreement amongst the values was, in all cases, within the statistics of counting.

For a few bones it was only possible to estimate their plutonium contents. The estimates were made in two ways: (1) from the values obtained in the analysis of a similar bone(s) and the wet weights of the bones, and (2) from the values obtained in the analysis of other sections of the same bone and the wet weights of the sections. An example of the former is the value for the sinuses where the value used was the mean of those obtained for the frontal-parietal, occipital-parietal, and temporal squamous bones. An example of the latter is the value for the diaphysis of the humerus where the mean of the values obtained for three sections was used to calculate the value for the other four sections. The amount of plutonium in those bones for which estimates were made was 6% of the skeletal burden. The assigned relative error of the estimated values was ± 25%.

Results and Discussion

The results obtained are given in detail in Table 1 and are summarized in Table 2. The relative error in the plutonium determinations was ±5% or less. Hence, the relative error for the values of relative plutonium concentrations, the last column in Table 1, is the same. The exceptions are those bones that were not analyzed in their entirety, e.g., the diaphysis of the femur (samples 1849–1855). In these cases the errors are given.

The amount of plutonium in the entire skeleton, 5.9 ± 0.2 kBq, was established by summing the amounts found in the unpaired bones and twice the amounts found in the paired bones. This is 54 ± 2% of the amount injected. The true error is probably larger than 0.2 kBq due to the fact that not all of the bones were analyzed, and lateral symmetry was assumed in the calculation of skeletal burden.

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Table 1. Wet and Ash Weights and the Relative Plutonium Concentrations for the Bones of CHR 40-010.

CHR Sample No.	Bone	Weight, g Wet[d]	Weight, g Ash[e]	Concentration Bq/ g Ash[e,f]	Relative Concentration[e,g]
1812	Frontal[a]-Parietal[b]	53.0	27.1	6.18	1.01
1813	Temporal squamous	16.2	8.41	5.80	0.95
1814	Occipital[a]-Parietal[b]	30.4	14.7	7.33	1.20
1815-1817	Sinuses[c]	48.8(0)	-	-	(1.09 ± .27)
1818	Mandible[a]	15.7	8.79	2.78	0.45
1819	Clavicle	18.3(0.65)	3.24	6.5 ± 0.5	1.05 ± 0.08
1820	Scapula	49.6	12.1	11.5	1.88
1821	Sternum[a]	23.8	1.69	31.7	5.19
	Ribs				
1822	1	5.5	1.06	13.2	2.16
1823	2	7.9	1.36	12.5	2.05
1824	3	9.2	1.65	12.3	2.01
1825	4	13.9	2.61	10.5	1.72
1826	5	16.1	2.76	12.7	2.08
1827	6	24.3	3.80	11.5	1.88
1828	7	22.7	4.00	11.9	1.95
1829	8	20.1	3.62	13.7	2.24
1830	9	17.4	2.78	14.5	2.37
1831	10	13.3	2.14	14.3	2.34
1832	11	6.2	1.03	12.6	2.07
1833	12	3.0	0.35	13.4	2.19
	Vertebrae, cervical[a]				
1834	Bodies	8.5(0.84)	1.11	23.5	3.85
1835	Processes	14.8(0.82)	2.78	11.0	1.80
	Vertebrae, thoracic[a]				
1836	Bodies	54.6	6.58	28.9	4.73
1837	Processes	35.2(0.90)	6.49	16.5	2.70
	Vertebrae, lumbar[a]				
1838	Bodies	39.5	4.46	26.2	4.29
1839	Processes	30.0(0.85)	4.54	12.4	2.03
	Innominate				
	Ilium				
1841	Anterior crest	13.2	1.93	29.9	4.89
1842	Posterior crest	15.2	1.84	32.8	5.37
1845	Sacroiliac area	44.2	6.30	20.9	3.42
1846	Body	76.1	15.96	15.1	2.47
1843	Ischium	34.8	5.52	21.9	3.58
1844	Pubis	21.4	3.27	24.8	4.06

Table 1 (continued)

CHR Sample No.	Bone	Weight, g Wet[d]	Weight, g Ash[e]	Concentration Bq/ g Ash[e,f]	Relative Concentration[e,g]
1840	Sacrum[a]	32.4	4.08	20.8	3.40
	Femur				
1847	Head and neck	22.5	5.46	13.1	2.14
1848	Greater trochanter	52.0	15.24	5.50	0.90
1849-1855	Diaphysis	163.2(0.37)	20.84	1.24 ± 0.18	0.20 ± 0.03
1856	Condyles	55.6	15.56	1.55	0.253
	Tibia				
1857	Proximal end	25.5	9.73	2.13	0.348
1858-1865	Diaphysis	103.5	51.74	0.65	0.106
1866	Distal end	13.0	4.88	1.22	0.200
	Fibula				
1867	Ends	13.9	3.29	1.83	0.300
1868	Diaphysis	26.4(0.21)	2.85	0.73 ± 0.16	0.12 ± 0.02
1869	Patella	13.8	2.95	1.85	0.303
	Feet				
1870	Tarsals	94.5	24.99	1.74	0.284
1871	Metatarsals	33.2	2.24	2.00	0.327
1872	Digits	17.8	2.90	1.63	0.267
	Humerus				
1873-74	Head	22.0	5.70	4.30	0.70
1875-1881	Diaphysis	55.2(0.84)	21.75	1.14	0.186
1882	Condyle	10.4	3.05	1.90	0.311
	Radius				
1883	Ends	8.7(0.70)	2.07	2.29	0.375
1884	Diaphysis	15.9(0.53)	4.17	0.73 ± 0.07	0.119 ± 0.011
	Ulna				
1885	Ends	13.0	4.43	1.34	0.219
1886	Diaphysis	17.9(0.46)	4.15	0.69 ± 0.08	0.112 ± 0.013
	Hand				
1887	Carpals	11.4(0)	-	-	(0.18)[h]
1888	Metacarpals	20.7	5.20	1.08	0.176
1889	Digits	20.5	4.81	1.30	0.212

[a] Half of these bones were analyzed.
[b] Part of the parietal was in sample 1812, the remainder in 1814.
[c] Paranasel and mastoid.
[d] When the whole of the sample was not ashed, the value in parentheses is the fraction that was.
[e] Where no error is given, the relative error in the value is less than ± 5%.
[f] 37 kBq/kg = 1 nCi/g.
[g] Relative concentration = concentration in bone/average concentration whole skeleton.
[h] Value assumed to be the same as that for metacarpals.

Table 2. Summary of Plutonium Distribution in the Skeleton of of CHR 40-010.

Bone(s)	Percent of Total Pu	Percent of Total Ash	Relative Pu Concentration
Frontal[a]-Parietal	5.7	5.6	1.0
Occipital[a]-Parietal	3.6	3.0	1.2
Temporal squamous	1.6	1.7	0.9
Sinus[a]	5.4 ± 1.3	5.0	1.1
Mandible[a]	0.8	1.8	0.4
Skull[a]	17.1 ± 1.7	17.1	1.00
Innominate	23.4	7.2	3.3
Vertebrae[a]	20.7	6.2	3.3
Ribs	11.8	5.6	2.1
Scapula	4.7	2.5	1.9
Clavicle	1.1	1.0	1.1
Sacrum[a]	2.9	0.8	3.6
Sternum[a]	1.8	0.4	4.5
Axial	66.4	23.7	2.8
Femur	8.5	20.3	0.4
Patella	0.2	0.6	0.3
Tibia	2.0	13.7	0.15
Fibula	0.5	3.4	0.15
Foot	1.8	6.2	0.3
Humerus	2.0	7.2	0.3
Radius	0.4	2.2	0.2
Ulna	0.4	2.8	0.15
Hand	0.5	2.7	0.2
Appendicular	16.3	59.1	0.27

[a] Values given are for half of this (these) bone(s).

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As expected for a radionuclide that deposits on bone surfaces, the plutonium concentrations in bones that are primarily trabecular were significantly higher than those that are primarily cortical. This is evident when comparing one part of a bone with another, one bone with another, and a group of bones with another. The ratio of the concentration in the femur head and neck (1847) to that in the diaphysis (samples 1849–1855) is 10.7; the sacrum (1840) to clavicle (1819) ratio is 3.24; and the torso to limbs ratio (Table 2) is 10.4.

There are other comparisons that show the relationship between plutonium concentration and bone type. For the long bones the ratio of the concentration in the ends to that in the diaphysis ranges from 2.0 for the ulna through 2.8 for the tibia to 4.0 for the femur. Of the long bones the ulna has the lowest percentage of trabeculae and the femur the highest. For the vertebrae the ratios of the relative concentrations, bodies to processes are 2.1, 1.8, and 2.1, respectively, for the cervical, thoracic, and lumbar groups.

In considering which bone should be taken in autopsy as being representative of the concentration in the skeleton, the clavicle would appear to be superior to any other. A rib has been the bone of choice in the past as it is readily available. This could continue to be the case, but as seen in Table 2 the mean concentration is twice that of the average concentration in the skeleton. A comparison of the values for the individual ribs (1822–1833) shows that which rib is taken is not important.

The conclusions that have been drawn from these data are qualified by the facts that the subject was suffering from a disease characterized in part by osteoperosis and that as a consequence of age her skeleton may still have been metabolically active.

Two teeth were analyzed, the left lower canine and a left second lower premolar. The plutonium concentrations (in ash) were 31 and 57 Bq/kg, respectively. These values are more than two orders of magnitude lower than the mean concentration in bone ash, 6110 Bq/kg.

The results obtained for soft tissues and hair are given in Table 3. With the exception of hair, the concentrations are based on the weights of the tissues at the time the remains were dissected. A significant fraction of the

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hair was cut into sections at 20 mm intervals beginning at the scalp, and the sections were analyzed for their plutonium content. Prior to analysis, the hair in each section was washed with detergent solution until microscopic examination showed the hair to be free of foreign material; it was then rinsed with water, air-dried, and weighed.

Table 3. Plutonium in Soft Tissues of CHR 40-010

Tissue	Concentration, Bq/kg[a,b]
Diaphragm	17.7
Muscle	7.8
Nerves	4.3
Eyes	46
Trachea and larynx	35
Skin	16.2
Costal cartilage	10.3
Nails	5.1
Hair section	
Proximal (20-40 mm)[c]	3.0 ± 0.7
Middle (140-160 mm)[c]	5.0 ± 0.8
Distal (260-280 mm)[c]	22 ± 3

[a] Where no error is given, the relative error is less than ± 5%.

[b] 37 Bq/kg = 1 pCi/g

[c] Distance from the scalp.

As expected, the concentrations of plutonium in the soft tissues are much lower than those in bone. The mean concentration in wet bone, 1770 Bq/kg, is about two orders of magnitude higher than the values given in Table 3.

As seen in Table 3, the concentrations of plutonium in the distal and middle sections of the hair are factors of 7 and 1.7, respectively, higher than the concentration in the proximal section. The shape of the curve obtained when the concentration in each section is plotted against the distance from the scalp, appears to reflect the concentration in blood as a function of time. Furthermore, it appears that the distal section was formed within a few months

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of the time of injection. The product of the growth rate for standard man, 0.5 mm/day, and the time between injection and death, 518 days, is 260 mm. However, analysis of all the data has not been completed.

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