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Strontium-90 Activity in Bones of the A-bomb Exposed in Hiroshima and Exhumed on Ninoshima Island

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Sr-90 activity was determined in the bone samples exhumed in 1955 and 1971 on Ninoshima, an island south of Hiroshima City. The bone samples were from those who died during approximately three weeks after exposure to the atomic bomb on August 6, 1945. Detectable concentrations up to 42 mBq $(gCa)^{-1}$ were found in 3 femora, 3 tibiae, 3 humeri, 2 ribs and 4 vertebrae out of 21 samples analyzed. Distribution of ^{90}Sr in the femur and tibia was examined. Although effects of exchange of this nuclide between bone and soil and loss of its activity by leaching are not well known, contamination due to the soil was estimated to be relatively small. From the results, possible existence of internally deposited ^{90}Sr was suspected.

INTRODUCTION

There are no known data on internal irradiation in Hiroshima. This is a report of fission products in samples of bones exhumed on Ninoshima Island in the southern part of Hiroshima Bay (see Fig. 1). The uranium bomb detonated over Hiroshima City on August 6, 1945[1]. In 1955, a number of bones of the dead were exhumed at Sen-Nin-zuka for re-burial and, in 1971, when bones of 220 subjects were also excavated from the ground of the Ninoshima Middle School used formerly for horse quarantine (Fig. 1). Sen-Nin-zuka is a mass tomb for the dead having been exposed to the bomb in Hiroshima, which was operated at that time by the army quarantine center. The horse quarantine was used for cremation, beside a regular crema-

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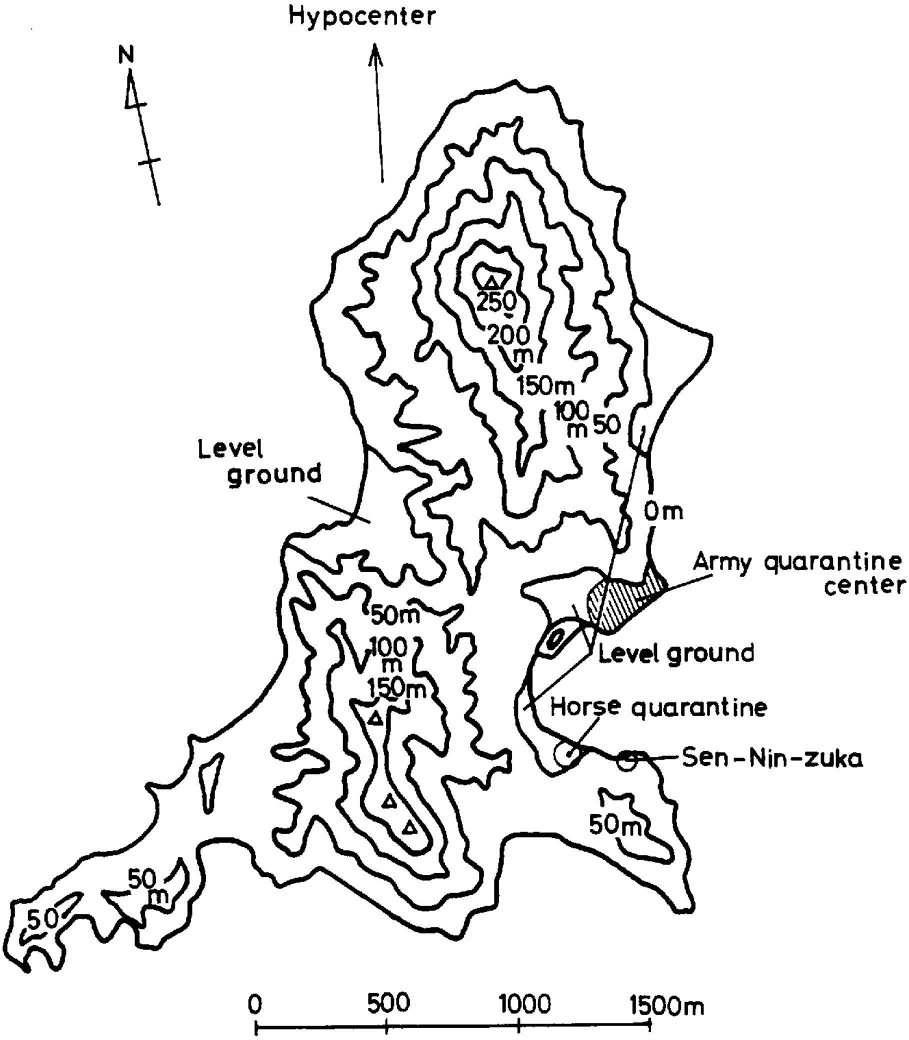

Fig. 1. An old map of Ninoshima Island.
The army qurantine center was 9.7 km south of the hypocenter, and approximately 5.6 km south of Port Ujina, Hiroshima. Bones were found at Sen-Nin-zuka in 1955 and in the former horse quarantine area in 1971.

tion facility on the island[2]. According to a comprehensive document, approximately ten thousand injured citizens fled by boat from Port Ujina, Hiroshima to Ninoshima Island between August 6 and 25. Being accommodated mainly in the quarantine center (Fig. 1), many of them died and were cremated or buried without cremation by the end of the month[2]. Thus the exhumed bones were from unidentified subjects who had been exposed to the atomic bomb in Hiroshima City and took refuge and died on the island during the latter part of 1945. Some of these bones were transferred to Hiroshima University for research purposes and presently determined for ^{90}Sr activity.

For local fallout, radiochemical studies were carried out as early as in September and October 1945 on a soil sample, collected from the eaves-trough of a private house in the western part of Hiroshima. The results showed the existence of fission products, *e.g.*, ^{89}Sr, ^{140}Ba, ^{140}La, etc.[3] There were some meteorological observations[4),5)]. Significance of local fallout was suggested later by some other workers[6),7)].

In this report, results of the ^{90}Sr determination of some of these exhumed bone are presented and possible uptake and deposition of the nuclide in bone are discussed.

MATERIALS AND METHODS

The bone samples consisted of five femora, six tibiae, three humeri, two sets of ribs and five sets of vertebrae. Twelve samples exhumed in 1955 were denoted as series 55 and nine samples excavated in 1971, series 46 (46th year of Showa). When received, they were air-dried and appeared to retain the original structure nearly completely, indicating that they were from bodies which had not been cremated. These samples were mostly adult bones as estimated from measurements of dimensions and were analyzed without further identification by age and sex. They were washed with deionized water and small amounts of soil on the bone were collected for analysis. The bone samples were further cleaned using a nail brush and a dilute detergent, rinsed with deionized water, and dried in an oven at 110°C for 48 h. Long bones were sectioned in halves, and the proximal half was ashed as described below; the distal halves being retained for further study. Rib and vertebral samples were treated in a similar manner. Dried bone samples were ashed at 550°C for 12 h. In the proximal half of five ashed long bone samples,

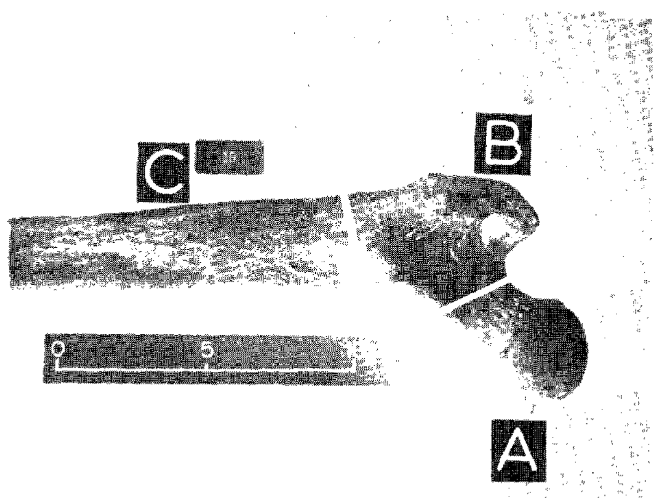

Fig. 2. A proximal half of an ashed femur, code 46-1.
A and B are denoted as "head" and C as "shaft" in text.

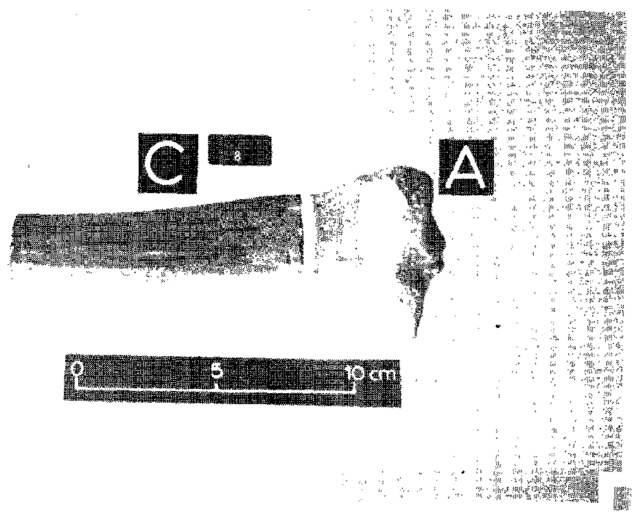

Fig. 3. A proximal half of an ashed tibia, code 46-9.
A and C are denoted as "head" and "shaft", respectively in text.

epiphyseal and diaphyseal parts were separated as shown in Fig. 2 and 3. Ashed material was pulverized to powder for homogenization using a Spex Mixer/Mill with a tungsten carbide ball and container. Aliquots of ash, 5 to 10 g in weight were subjected to a modified radiochemical procedure for determining ^{90}Sr[8]. Detection limit (DL) was calculated to be about 5 mBq $(gCa)^{-1}$ from three times the standard deviation of counting rate in a blank sample after the ^{90}Y milking and assuming an ash weight of 5 g.

RESULTS AND DISCUSSION

Results of the determination are shown in Table 1 as of the time of analysis, *i.e.* February 1981, without correction for physical decay. The ^{90}Sr activity ranged between lower than DL and 41.9 mBq $(gCa)^{-1}$. Means and standard deviations of all the results in each type of bone were as follows: femur, 13.8 ±14.5 (n = 5); tibia, 9.6 ±10.7 (n = 6); humerus, 11.8 ±8.7 (n = 3); rib, 16.1 ±9.6 (n = 2); and vertebra, 21.3 ±16.9 (n = 5) mBq $(gCa)^{-1}$.

The average ^{90}Sr concentration in the bone samples exhumed in 1955 and 1971 was 15.1 and 13.3 mBq $(gCa)^{-1}$, respectively. Most of the ^{90}Sr concentrations found were incidentally in the range of concentrations reported for the adult bone from the general Japanese population with an average of approximately 27 mBq $(gCa)^{-1}$ during the period between 1961 and 1971[9]. The comparison between the data, though, will not be meaningful since sources of exposure are thought to be different.

The mean ^{90}Sr concentration in different types of bone samples was as follows: 8.0 ±6.8 in the long bone (n = 8), 22.9 (n = 1) in the rib and 31.3 ±13.9 (n = 3) mBq $(gCa)^{-1}$ in the vertebra which were exhumed in 1955. In the 1971 samples, this was 16.4 ±14.5 (n = 6),

Table 1. ^{90}Sr activity concentrations in the bone samples of deceased A-bomb exposed in Hiroshima on August 6, 1945, exhumed on Ninoshima Island in 1955 (series 55) and 1971 (series 46).

Bone	Sample code	^{90}Sr concentration mBq $(gCa)^{-1}$	Mean: All results	Mean: Results above DL
Femur	55-2	< DL	13.8 ±14.5	20.6 ±15.8
	55-3	13.9 ±2.0	(n = 5)	(n = 3)
	46-1	9.2 ±1.4		
	46-2	38.6 ±3.0		
	46-3	< DL		
Tibia	55-13	< DL	9.6 ±10.7	17.4 ±10.3
	55-14	6.9 ±1.2	(n = 6)	(n = 3)
	55-16	< DL		
	46-9	< DL		
	46-10	17.8 ±1.6		
	46-11	27.4 ±2.9		
Humerus	55-29	5.7 ±1.3	11.8 ±8.7	11.8 ±8.7
	55-33	21.7 ±5.4	(n = 3)	(n = 3)
	55-34	7.9 ±1.2		
Rib	55-53	22.9 ±1.4	16.1 ±9.6	16.1 ±9.6
	46-15	9.3 ±1.2	(n = 2)	(n = 2)
Vertebra	55-51	15.6 ±1.7	21.3 ±16.9	25.6 ±16.1
	55-54	36.3 ±6.7	(n = 5)	(n = 4)
	55-68	41.9 ±0.3		
	46-25	8.4 ±3.2		
	46-26	< DL		

9.3 ±1.2 (n = 2) and 6.3 ±3.0 (n = 2) mBq $(gCa)^{-1}$ in the long bone, rib and vertebra, respectively. No apparent influence of the length of burial, 10 and 26 years for series 55 and 46, respectively, was observed on the concentration level in these bones.

Since the different bones were not necessarily from the same individuals, the data may not warrant further comparison in radioactivities among the long bones, ribs and vertebra in detail. Discussion of the distribution of ^{90}Sr in bone will, therefore, be made later concerning some results obtained using single long bones.

The soil collected on cleaning was analyzed for ^{90}Sr and found to have a concentration of 14 mBq (g dry soil)$^{-1}$. Contribution of the soil, however, to any of the ^{90}Sr measurements was estimated to be less than 0.1 mBq $(gCa)^{-1}$, even when assuming that up to fifty milligrams of soil still remained in a sample after cleaning.

The bone samples exhumed in 1971 are reported to have been found at a depth of about 1 m from the surface of the school ground. For the 1955 samples, less information is available on the condition during burial. Some soil samples which were taken at the time of the 1955 exhumation were also analyzed. Detectable ^{90}Sr activity was found in a sample from a depth of about 1 m, close to the area where the bones were excavated. The concentration level was less than that found in the soil attached to bone.

At present there are only fragmentary data on any effect of exchange of ^{90}Sr between the bone samples and surrounding soil or leaching of the nuclide during burial.

If contamination of bone samples had occurred due to the ^{90}Sr in the surrounding soil during 10 (series 55) or 26 (series 46) years of burial, concentrations of ^{90}Sr activity in the same type of bone would have become similar and shown a certain "equilibrium" level. The results for the bone shown in Table 1, however, show that this was not the case: variations in the activity concentrations were seen in each type of bone, the femur, tibia, humerus and vertebra.

As a possible means to determine whether or not the detected bone ^{90}Sr activity was incorporated before death, intra-bone distribution of ^{90}Sr was considered to be useful. Three femoral and two tibial samples were divided as shown in Figs. 2-4 and the results are listed in Table 2. The concentration ratio between the head and shaft was 1.7 in a tibia, code 46-10. The head-to-shaft ratios in the two femoral samples, code 46-1 and 55-3 were, 2.9, and about 12, respectively.

From literature on fallout ^{90}Sr concentrations in bone in 1961, it was shown that an average ratio, 2.6 was observed between the upper extremity and the shaft of the adult femur on the basis of calcium weight[10]. From experimental animal data, administered alkaline earths including ^{90}Sr are concentrated in active growth sites of bone, but the distribution tends to be more even with a continuous uptake[11),12]. The pattern of intra-bone distribution of

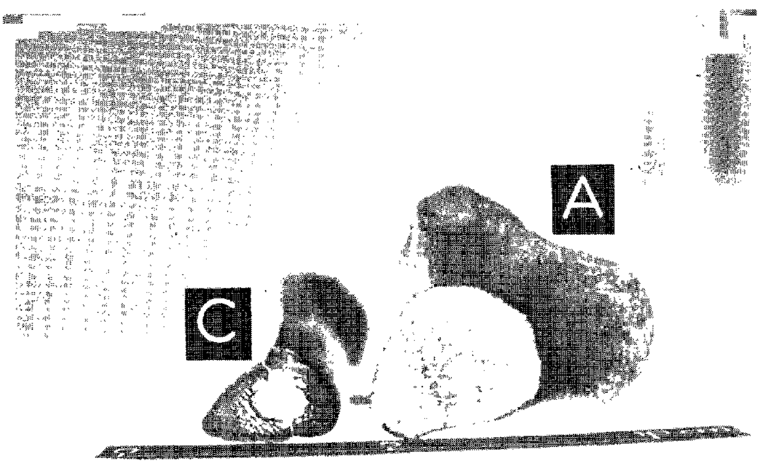

Fig. 4. Cross sections of the ashed tibia, code 46-9, viewed upward from the distal side. Small cracks in the shaft were formed on ashing.

Table 2. Concentration ratios between the head and shaft of some long bone samples.

Sample code	Bone	Part	^{90}Sr concentration mBq $(gCa)^{-1}$	Concentration ratio Head/Shaft
55-3	Femur	Head	28.4 ±4.5	(12 ±7)
		Shaft	2.3*	
46-1	Femur	Head	15.2 ±3.3	2.9 ±0.8
		Shaft	5.2 ±0.8	
46-3	Femur	Head	< DL	–
		Shaft	< DL	
46-9	Tibia	Head	< DL	–
		Shaft	< DL	
46-10	Tibia	Head	24.3 ±1.6	1.7 ±0.3
		Shaft	14.0 ±2.4	

*) Lower than DL.

^{90}Sr presently detected in the proximal half of the one tibial and two femoral samples appears consistent with that expected in a single or relatively short intake of the radionuclide.

For other femoral (code 46-3) and tibial (code 46-9) samples, the radioactivity was found to be lower than DL both in the head and shaft. This fact supports the assumption that contamination due to the surrounding soil was negligible.

From all the results stated above, it is suggested that the ^{90}Sr activity in the exhumed bone samples might have been internally deposited by inhalation of fission debris and/or by ingestion of contaminated water. If so, the variation in bone ^{90}Sr concentrations in this study suggests that intakes must have varied among the deceased.

In conclusion, the determinations of ^{90}Sr in the exhumed bone samples from the A-bomb exposed in Hiroshima who died within a few weeks of exposure and were buried on Ninoshima Island suggest the possible presence of ^{90}Sr which was incorporated and deposited in bone. The level of ^{90}Sr activity concentration appears to have been too low to warrant estimation of doses in view of radiation effects to bone tissues in these subjects. This report provides data, for a first step, to discuss the possibility of internal exposure in the A-bomb survivors due to the intake of fission products.

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