the experimenter so that the light fell on the dial behind which was a light-sensitive germanium diode. When the light fell on the dial, a recording pen was deflected. The pointer deflections and resets were also recorded.

Each subject was instructed to detect as many signals as he could and to reset the pointer as quickly as possible. At the end of each session each subject was told the number of signals he had detected and his reset times. No mention was made of the experimenter's interest in the observing responses, and subjects were told only that they could use the light to illuminate the dial.

Inspection of the records of the tenth session shows marked consistency of observing behavior within subjects but great differences between subjects. Data showing a portion of each subject's responses on session 10 are presented in Fig. 1.

The magnitude of deflection away from the "no-response" base line depended upon the proximity of the light to the dial, and it can be seen that there was both intra- and intersubject variability.

Two of the subjects, *S*-2 and *S*-3, exhibited behavior much like that reported by Holland—that is, the observing responses increased as signal time approached. The record of one subject, *S*-3, corresponds almost exactly to those presented by Holland.

The observing responses of the other three subjects, *S*-1, *S*-4, and *S*-5, were relatively continuous and unlike those obtained by Holland. This was particularly true of *S*-1.

While Holland found that the temporal manner of signal presentation controlled the observing behavior of subjects, the results of the present experiment indicate that this behavior differed between subjects under identical experimental conditions. Some subjects moved their head and eyes away from the display immediately after a signal and then fixed their eyes on the display again as the signal time approached. Other subjects apparently fixed their eyes on the display in a fairly continuous manner. The differences from Holland's results may be due to the measurement of a different response or to differences between subjects. It is also possible that the relatively continuous observing shown by *S*-1, *S*-4, and *S*-5 was due to the ease of the observing response. It has been shown (*3*) that there is no scallop in the observing rate curves for fixed-interval schedules when Holland's technique is used and when the key tensions are very light. However, the delays after detection and before responding increase with key tension.

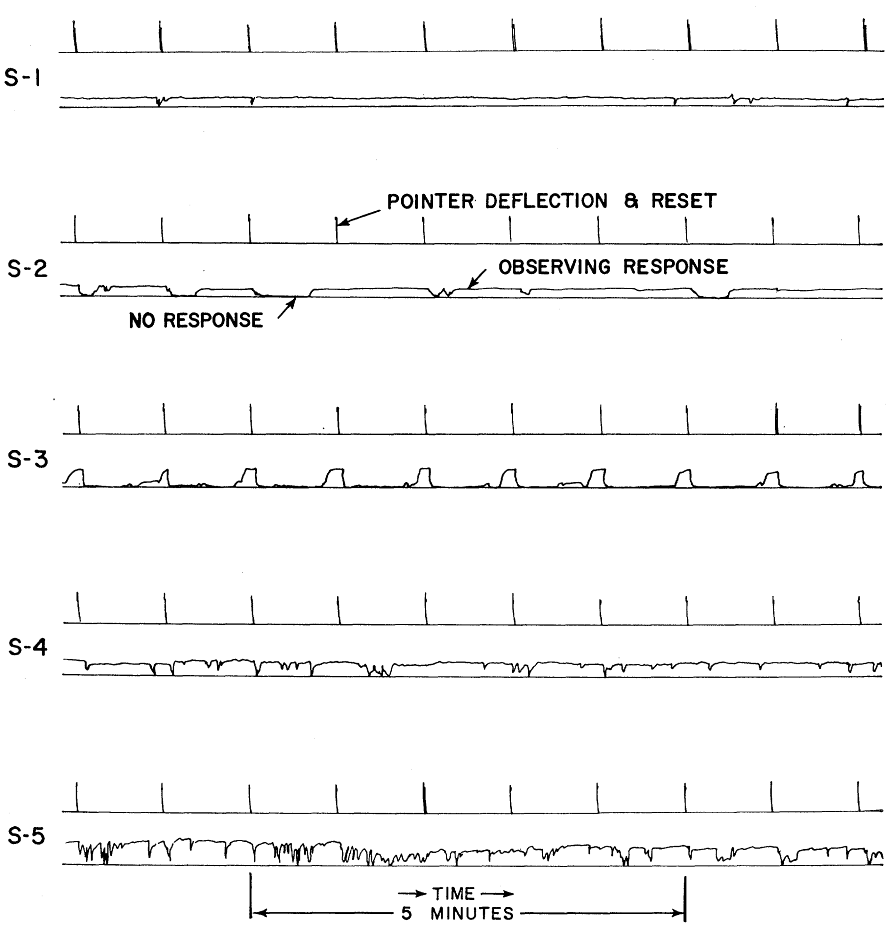

Fig. 1. Characteristic response records of each subject for a 1-minute fixed-interval schedule of pointer deflections. The records were obtained on the last (tenth) session.

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6 March 1958

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 bones 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 cadavers, and composites from 16 localities, each representing equal weights of bone ash from 4 to 38 individuals.

The analyses were performed by an emission spectrographic technique modified from that of Turekian and Kulp (*2*). The standards 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 ± 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 bones 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 composited by locality 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 knee-elbow 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^{90}/Ca ratio throughout the lifetime of the individuals.

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

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

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

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 ± 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 Stitch (*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 ± 0.1. The value $(\%Sr/\%Ca) \times 10^3$ in average rock or soil is 7 ± 1 (*8*). The discrimination factor between soil and skeleton for the strontium/calcium ratio is therefore 15 ± 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

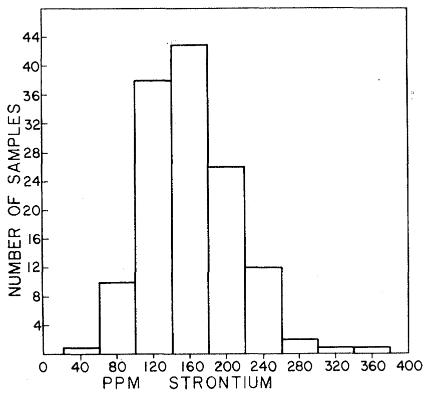

Fig. 1. Histogram of common strontium in ash of whole skeleton from New York City.

vegetables, the predicted over-all discrimination factor would be 16. This figure is in good agreement with the geochemical value of 15 ± 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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4. Lamont Geological Observatory contribution No. 304. This research was carried out under contract AT(30-1)-1656 between the U.S. Atomic Energy Commission and Columbia University. The criticisms and suggestions of Dr. K. K. Turekian are appreciated. We acknowledge the assistance of Mr. P. Hazlett.

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19 February 1958