and longer words consequently are given proportionately longer presentations. The rate of discrimination then need not vary with the length of the word.

Habits and Performance Factors in the Perception of Words

Vision and audition share the beneficial effects of frequency of past usage and of restriction of alternatives upon ease of perception of words. Frequency of past usage may be considered to develop habits of responding to a particular stimulus with a particular response. The more frequently a word has been used in the past, the more readily it is recognized. The restriction of alternatives in a particular situation operates differently. It does not change the perceiver's habits, which are based on his history of past usage. Rather it is a "performance factor" which influences the use made of already formed habits. The smaller the number of alternatives included in the set of words expected by the perceiver, the more ready he can be to use each of the corresponding habits. Thus both frequency of usage and restriction of alternatives make it easier to give a complete response to a stimulus word on the basis of fragmentary discriminations.

A Practical Suggestion

Our survey of the factors governing intelligibility suggests a way in which more highly intelligible alphabetic equivalents might be selected. First let us see where the current alphabetic equivalents are located on Fig. 3. The words of the English telephone list (Andrew, Benjamin, Charlie, David, and so on) have an average length of 5.7 letters and an average frequency of 254 on the Lorge magazine count. These values determine the location labelled *1* near the lower right corner of the surface. Words of the joint U.S.–British radiotelephone list (the familiar Able, Baker, Charlie, Dog, and so on) have an average length of 4.1 letters and an average frequency of 355; this group centers around the 2 on the surface. (In both cases the individual words scatter rather widely around the average values, considerably more widely than the cross-hatching indicates.) Now these lists were not deliberately selected to be on the lower right corner of the diagram, because the studies on effects of frequency of usage and word length had not yet been done when the lists were prepared. The main criterion employed was that the words be common, familiar ones. In the case of the U.S.–British list, empirical tests were used to choose highly intelligible words from a pool of familiar items. The use of the criterion of familiarity leads to words of high frequency and low length, since familiarity implies high frequency and since, in turn, frequent words tend to be short. It should be noted, however, that although frequently used words tend to be short, there are many frequent words of considerable length. The figure indicates that by selecting longer words toward the upper right corner of the surface, the region labelled *3*, a gain of over 6 decibels in resistance to noise might be achieved. In fact, wartime tests of intelligibility demonstrated that many of the items of the U.S.–British list could be improved. Twenty-two changes were suggested on the basis of empirical tests; 19 of the changes substituted items of greater length for the original words. This improved list, which was never adopted, had an average length of 6.4 letters and an average frequency of 56. Length was gained, though with some loss in frequency.

Now that the effects of frequency and of length on intelligibility have been made explicit, it should be possible to choose items from a pool of words that are both frequent and long. The diagram, of course, presents only average thresholds. Within any region, some words are more intelligible and some are less intelligible than would be predicted on the basis of their frequency and length. Empirical tests will therefore be required to determine whether the most intelligible items from the pool of longer words are clearly superior to the most intelligible of the shorter words. If they are, we may find Mr. Sedgwick spelling his name on a future occasion in this way: "*S* as in 'student,' *E* as in 'examination,' *D* as in 'department,' *G* as in 'grandmother,' *W* as in 'welcome,' *I* as in 'industry,' *C* as in 'companion,' *K* as in 'kindness.' "

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Strontium-90 in Man, II

Walter R. Eckelmann, J. Laurence Kulp, Arthur R. Schulert

The continuation of nuclear tests makes a thorough understanding of the movement and uptake of strontium-90 a necessity while the levels in man and his environment are still relatively small compared with natural background radiation. In a previous publication (*1*) the first data on a world-wide analysis of strontium-90 in human tissue were presented. The study of the geochemical distribution of strontium-90, of its transfer through the food chain, and of its variation in human populations has continued (*2*). This article (*3*) summarizes over a thousand analyses of human bone and interprets these data in terms of present concentrations of strontium-90 in the various critical phases of the geosphere and biosphere. The new data permit a closer definition of the average concentration of strontium-90 in a large part of the human race, the geographical and dietary variation, the increase in the concentration with time, and the distribution in urban populations. From the existing data, an attempt is made to predict future levels under specified conditions.

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Experimental Data

The methods employed for the radiochemical separation of strontium-90 from human bone and the low-level radiometry have been described in detail elsewhere (*4*). The vegetable samples are treated in essentially the same way after dry ashing, although a strontium-85 spike is introduced in each sample for yield determination because of the variable character of the material. The bone assays were done at the Lamont Geological Observatory and at two commercial laboratories: Isotopes Incorporated, Westwood, New Jersey, and Nuclear Science and Engineering Corporation, Pittsburgh, Pennsylvania. Frequent intercalibrations assured reliability of the results from the different laboratories.

Autopsy samples of human bone are now being received from about 30 stations in a world-wide network (*5*). During this period of the investigation an attempt was made to obtain samples that were equally distributed with regard to the age of the individual at death. An attempt was also made to obtain maximum spread in geographic and dietary setting, but the restriction in the location of medical centers has limited the samples largely to urban populations.

The results reported in this article include those given in the previous report with the exception of samples which contained less than 1.0 gram of calcium. Very small samples are subject to large statistical errors and are more sensitive to slight contamination. The elimination of such samples at an arbitrary calcium level does not cause preferential selection of the data, reduces the number of samples by less than 5 percent, and does not seriously affect the final averages. Currently, only samples containing more than 1.0 gram of calcium are assayed for strontium-90. Also omitted are data reported in the previous article for the 49-year-old Vancouver (British Columbia) female (died October 1955; 8.3 micromicrocuries of strontium-90 per gram of calcium) and for the 34-year-old Japanese man (died June 1955; 4.05 micromicrocuries of strontium-90 per gram of calcium). Each of these two results is greater than the mean value for adults in 1955 by a factor of 50 to 100 and larger than the next nearest adult value by a factor of 5 to 10. They may be real but rare high values. On the other hand, there are cogent reasons for rejecting them as artifacts: (i) Clinical data indicate that the individuals were city dwellers. Data on urban foods make it extremely unlikely that these adults had a sustained diet of 100 times the average strontium-90 concentration. (ii) These samples now lie about 100 standard deviations from the mean (see discussion later in this article on the distribution curve). (iii) These were among the first few batches of samples analyzed commercially. (iv) When the medical history of the Vancouver patient was checked, it was found that she had carried a radium seed. Although this last finding should not affect the strontium-90 analysis if the analysis is properly done, it presents a possible explanation of the high value, particularly since the analysis was made in the early phase of the work. Even if these two anomalous samples were included, this would not affect any of the conclusions which are drawn from the regional averages.

All results are reported in micromicrocuries of strontium-90 per gram of calcium. Samples which were reported by the analysts as "equal to or less than" a certain number are assumed to have that value (that is, "$\leqq 0.02$" is taken as 0.02) in computing the averages. Therefore, the reported averages are maximal. If all such samples are eliminated it would change the general averages by less than 10 percent but would reduce the total number of samples by about one-quarter.

These measurements have been made in an attempt to determine the average concentration of strontium-90 in the whole skeleton of a man. In the world-wide sampling, however, only a single bone is obtained, generally either vertebrae, rib, or femur shaft. Although stable-strontium/stable-calcium ratios are essentially constant among the bones of the skeleton, experiments conducted by Schulert and Laszlo (*6*), in which single intravenous doses of calcium-45 and strontium-85 were given to ten patients, followed by analyses at death (1 to 125 days after administration), show large but consistent differences in the amount of strontium-85 per gram of calcium. The stable element result reflects long-term continuous ingestion on a near-constant diet of stable-strontium/stable-calcium. The tracer experiment shows the maximum differences to be expected in the adult skeleton for a dose of radioisotope over a short time interval. Since the bones of adults are not in equilibrium with the strontium-90 in the diet and since there is a long turnover time for mature bone, the strontium-90 concentrations in the various bones of the skeleton should also be different. Therefore it is necessary to define the normalization factors that are required to convert the analytical data on single bones to average strontium-90 concentrations for the whole skeleton.

Table 1. Normalization factors from single bone to average skeleton (adults).

Sr^{85} single dose in man: Previous estimate (*1*) 1 case	Sr^{85} single dose in man: Present estimate (*6*) 10 cases*	Sr^{90} distribution in 10 New York cadavers* (*7*)
	Vertebrae	
4.2	4.8	3.4
	Rib	
2.0	2.1	1.5
	Long bone shaft	
0.7	0.6	0.8

* The standard deviation is about ± 25 percent of the value.

Table 1 gives these normalization factors for the strontium-85 single-dose experiments and for natural strontium-90 in ten cadavers from New York (*7*). The distribution of strontium-90 is more uniform than that in the extreme case of the single strontium-85 dose, but it shows significant differences with respect to the various bones of the skeleton. The strontium-90 factors, rather than those for the strontium-85 experiments, have been used in correcting all individual measurements to the whole-skeleton value for all samples from individuals 20 years of age and older.

In individuals of from 0 to 19 years of age, the strontium-90 distribution is more nearly uniform, since most of the strontium-90 has been introduced into the skeleton by bone growth rather than by exchange and remodeling, as is the case with adults; hence, no correction has been made. Clearly, however, this is only an approximation, since children's bones are still far from being in equilibrium with their diet. Empirical evidence that this treatment of the data more nearly reflects the true situation is found in the consistency of the data, in similar latitudes, for adults and children, represented by different bones. Samples are now being obtained to verify this point directly.

For convenience, the time intervals chosen to show the progressive increase in concentration of strontium-90 begin on 1 July of each year. The impact of the major nuclear tests of the spring of 1954 did not begin to show up in human bone until after 1 July of that year. The present discussion covers the period from 1 July 1953 to 30 June 1957.

The analytical errors on the individual measurements range from 2 to 50 percent, depending on the activity, but most

Table 2. Average strontium-90 content in man, 1 July 1955 to 30 June 1956 and 1 July 1956 to 30 June 1957. All values are given in micromicrocuries of strontium per gram of calcium, normalized to the whole skeleton. The figures in parentheses give the number of samples in the category.

Location	Age at death (yr)								
	0–4	5–9	10–19	20–29	30–39	40–49	50–59	60–80	20–80 (average)
					1955–56				
North America	0.56(10)	0.44(4)	0.20(13)	0.09(34)	0.07(38)	0.06(14)	0.04(17)	0.07(34)	0.070(137)
South America	0.33(12)	0.19(16)	0.14(26)	0.07(48)	0.06(58)	0.08(45)	0.07(18)	0.11(15)	0.073(184)
Europe	0.42(30)	0.27(19)	0.23(46)	0.06(70)	0.10(59)	0.06(8)	0.16(1)	0.09(3)	0.078(140)
Asia		0.10(2)	0.20(9)	0.06(35)	0.07(32)	0.11(11)	0.13(13)	0.20(4)	0.085(95)
Entire world	0.43(52)	0.25(41)	0.20(94)	0.068(187)	0.076(187)	0.079(78)	0.077(49)	0.091(56)	0.076(556)
					World average 1955–56 = 0.15				
					1956–57				
North America	0.67(30)	0.69(17)	0.38(15)	0.07(14)	0.06(9)	0.08(16)	0.05(5)	0.07(18)	0.070(62)
South America	0.16(3)	0.20(1)	0.19(5)	0.03(5)	0.02(2)	0.03(2)	0.06(3)	0.01(1)	0.034(13)
Europe	0.65(2)	0.34(4)	0.34(9)	0.06(20)	0.07(4)	0.04(6)	0.06(1)	0.08(2)	0.059(33)
Africa			0.06(2)	0.03(2)	0.03(3)	0.04(4)			0.035(9)
Asia	0.93(1)	0.12(2)	0.32(2)	0.06(8)	0.04(6)	0.12(8)	0.06(5)	0.05(5)	0.070(32)
Australia	0.75(3)	0.60(2)			0.03(3)	0.03(4)	0.03(3)		0.030(10)
Entire world	0.64(39)	0.57(26)	0.30(33)	0.059(49)	0.047(27)	0.070(40)	0.052(17)	0.065(26)	0.060(159)
					World average 1956–57 = 0.20				

samples have an error of the order of 5 to 10 percent. In general, the analytical error is quite small compared with the degree of uncertainty about the relation of an individual bone to the whole skeleton. Variations in the strontium-90 concentration within a given bone and among similar bones of the same individual show a standard deviation of about ±25 percent. Since this effect should average out in a large number of samples, the uncertainty in the national or global averages is probably controlled by variation in local fallout and diet rather than by variability in sampling procedure.

Regional Averages and Age Dependence

The strontium-90 content of the average human bone for each continent, as a function of age, for 1955–56 and 1956–57 is given in Table 2. It is evident that there is no significant difference in the age groups of 20 years and older. The differences from one 10-year age group of adults to another at the same station do not exceed the mean by more than about 10 percent for those cases where a large number of samples is available. Therefore, the adult samples may be pooled for statistical purposes. The ratio of the strontium-90 level in young children (0 to 4 years) to that in adults rises from about 6 to 1 in 1955–56 to 10 to 1 in 1956–57, reflecting the more rapid approach to equilibrium of the children due to the growth of new bone. It is noted that in 1956–57 the highest values are found in North America, while values for South America, Africa, and Australia are about half of this, with those for Europe in between. For all samples, the value for the average female is about 15 percent higher than that for the average male. Since the data include a thousand individuals nearly equally divided with respect to sex, this result is considered significant.

The "world averages" were computed by weighting the average for each age group by the fraction of the world population in that age group. The Asian samples come only from Japan, Taiwan, and India. But if Taiwan can be presumed to represent Southeast China, a large fraction of the people in Asia are included. The levels in Russia are very probably higher, due to the proximity to test sites. Since the differences in the average bone level from one station to another seldom exceed a factor of two, the calculated "world average" is relatively insensitive to the distribution of the sample location. Finally, the stations in the United States, Europe, Japan, China, and India may represent 70 to 80 percent of the world's population.

Table 3 shows that the strontium-90 level in human beings is more uniform than the total fallout. One reason for this, as suggested to us by Lyle Alexander, of the U.S. Department of Agriculture, is the widespread distribution of milk products from the United States and northern European countries.

The world-wide average for the urban world population in 1955–56 is seen to be about 0.15 micromicrocuries of strontium-90 per gram of calcium, which represents a level of about 0.076 in adults and 0.43 in young children. In 1956–57 these figures are 0.20, 0.060 and 0.64, respectively, showing an increase in the young children of 50 percent and in the world average, of about 30 percent.

Individual Stations and Time Effect

Table 4 lists the average values for children aged 0 to 4 and 5 to 9 and for adults, as a function of time, in the stations from which analyses have been completed. Significant comparison of certain localities can be made only if the samples are numerous, because of the individual biological variation. Values

Table 3. Comparison of variations, with latitude, in strontium-90 content of human bone and in total fallout.

Latitude	Human bone (Av. for 1955–57) ($\mu\mu c$ Sr^{90}/g Ca) — Age at death		Soil, (June 1956)* (mc/mi^2)
	0–4	Adults	
60–40°N	0.55	0.07	~8
40–20°N	0.68	0.085	9.4
20–0°N	0.32	0.075	3.9
0–20°S		0.05	2.0
20–40°S	0.46	0.06	2.6

* From remarks prepared by Merril Eisenbud, manager of the New York Operations Office, U.S. Atomic Energy Commission, for hearings of the Joint Committee on Atomic Energy, 27 May 1957.

Table 4. Average strontium-90 concentration in man for three periods (1 July 1954 to 30 June 1955; 1 July 1955 to 30 June 1956; 1 July 1956 to 30 June 1957) for each station. All values are given in micromicrocuries of strontium-90 per gram of calcium, normalized to the whole skeleton. "Adult" represents samples of individuals who died at 20 years or older. The figures in parentheses indicate the number of samples in the category.

Location	Bone	1954–55			1955–56			1956–57		
		Age at death (yr)			Age at death (yr)			Age at death (yr)		
		0–4	5–9	Adult	0–4	5–9	Adult	0–4	5–9	Adult
Boston	Vertebrae	0.78(2)			0.61(3)	0.22(1)		0.69(25)	0.71(15)	0.06(19)*
New York	Mixed	0.17(1)		0.05(44)			0.05(38)			
Denver	Vertebrae	0.29(3)			0.48(4)	0.1(1)	0.08(44)	0.67(3)	0.59(1)	0.06(6)
Houston	Mixed	0.32(2)		0.15(23)	0.82(3)		0.14(11)			
Vancouver	Tibia	0.32(2)	0.07(2)	0.08(16)			0.05(29)	0.42(2)	0.72(2)	0.08(21)
Puerto Rico	Vertebrae			0.08(15)	0.27(2)		0.07(16)		0.48(1)	
Venezuela	Rib		< 0.17(1)		0.33(12)	0.34(8)	0.09(51)			
Colombia	Rib → Vertebrae			0.09(2)			0.04(7)			0.02(2)
Argentina	Vertebrae									0.05(2)
Chile	Rib		0.19(3)	0.10(13)		0.04(8)	0.07(86)	0.16(3)	0.20(1)	0.03(9)
Brazil	Rib		0.07(1)	0.10(4)			0.05(41)			
Australia	Rib							0.75(3)	0.60(2)	0.03(10)
Taiwan	Mixed	0.2(1)		0.03(2)		0.14(1)	0.08(18)	0.93(1)	0.09(1)	0.04(4)
India	Rib		0.32(2)	0.10(6)		0.06(1)	0.07(58)			0.08(11)
Japan	Rib						0.14(19)		0.14(1)	0.08(15)
Iran	Femur									0.03(2)
Denmark	Vertebrae	0.18(1)	0.20(1)	0.03(2)		0.22(1)	0.05(12)		0.36(1)	0.04(7)
England	Vertebrae				0.74(5)	0.18(6)	0.04(14)	0.31(1)		0.06(11)
Germany	Femur	0.31(3)	0.10(2)	0.11(12)	0.30(20)	0.18(6)	0.08(79)			0.05(11)
Italy	Rib			0.09(4)	0.37(1)		0.13(14)			
France	Rib						0.05(5)			
Switzerland	Vertebrae	0.53(3)		0.09(5)	0.60(4)	0.47(6)	0.09(17)	0.98(1)	0.44(2)	0.09(10)
Union of So. Africa	Rib									0.04(11)

* Femur

for Houston, Texas, appear to be significantly higher than those for other North American cities for 1954–56. Values for adults in Chile, South Africa, and Australia are lower than those for adults in Northern Hemisphere stations by a factor of two. It is noted that the adults show a small apparent decrease in strontium-90 content during the past year. This is primarily due to the variation in stations represented in the two years (for example, the bones of individuals in Houston, which had higher-than-average values in 1954–56, are not represented in 1956–57). The results do show that the rise in children is much greater than that in adults. This is a striking reflection of the fact that, whereas adults are merely exchanging a small fraction of their skeleton each year, the children are building new bone in equilibrium with their diet, in addition to exchange.

Comparative strontium-90 data for England have been obtained by Bryant *et al.* (*8*) from a dozen localities. For 1955–56 their data show an average of 0.77 micromicrocuries of strontium-90 per gram of calcium in 18 samples, 0.22 micromicrocuries of strontium-90 per gram of calcium in 3 samples, and 0.08 micromicrocuries of strontium-90 per gram of calcium in 19 samples for the 0 to 4, 5 to 9, and adult age groups, respectively. The averages agree with those reported in Table 4, within the standard deviation of each, and they are as high as those of any comparable area in North America. The higher average rainfall in the British Isles apparently compensates for the greater distance from the Nevada test site. In addition, westward-moving Russian tropospheric debris would presumably contribute more fallout to Great Britain than to the United States.

Table 5 compares the change in levels of strontium-90, with time, for cumulative New York rainout, New York and Wisconsin milk, bones of young children (age 0 to 4) and of adults in northeastern United States, and bones of young children from North American stations. These sets of bones were taken because they represent the largest number from one area or continent over the period of interest. The values for milk and for the cumulative fallout go up proportionally, whereas those for bones lag behind, due

Table 5. Increase in strontium-90 levels in various materials. The figures in parentheses represent the number of samples in the category.

Sample	Units	1953–54	1954–55	1955–56	1956–57
Cumulative rainout (New York)*	mc/mi^2	5	9	18	28
Milk (New York)†	$\mu\mu$c Sr^{90}/g Ca	0.8	1.25	2.4	3.5
Milk (Wisconsin)†	$\mu\mu$c Sr^{90}/g Ca	1.2	2.0	3.0	4.3
Bones of children (0 to 4 yr) (New York and Boston)	$\mu\mu$c Sr^{90}/g Ca	0.28(5)‡	0.57(3)	0.61(3)	0.69(25)
Bones of children (0 to 4 yr) (North America)	$\mu\mu$c Sr^{90}/g Ca	0.28(5)‡	0.38(10)	0.56(10)	0.67(30)
Bones of adults (New York and Boston)	$\mu\mu$c Sr^{90}/g Ca	0.02(3)‡	0.05(44)	0.05(38)	0.06(19)

* Data from New York Operations Office of U.S. Atomic Energy Commission and Lamont Geological Observatory.
† Data from New York Operations Office interpolated from reports (*10*).
‡ Data of Libby (*12*).

to the delay in reaching equilibrium with the diet. Thus, although the fallout and milk samples increased three-and-one-half- to sixfold from the end of 1953 to the end of 1956, the bone levels increased two- to threefold.

Distribution in Single Population Group

In order to predict the fraction of the human population that will have any given concentration of strontium-90, it is necessary to examine the statistical distribution of strontium-90 in certain well-defined groups. Consider first only people living in cities or those who obtain their food from central distribution centers. The greatest spread will be obtained by grouping together adults of all ages from all localities. Figure 1 is a histogram showing the distribution of all adult samples in 1955–56. There are a number of factors which tend to make the distribution for adult groups, even at one site, much larger than will actually be the case at equilibrium. These include biological variation from one bone to another in a single individual and the different rates at which individuals equilibrate their bones with their diet. Thus, a histogram of adult samples would be considerably skewed to the right. Such a distribution will probably become narrower as equilibration proceeds. The group in which the equilibrium situation is likely to be most closely approximated is that of young children (Fig. 1), who have strontium-90 more uniformly distributed in their bones. Thus, although the distribution curve for all adults in 1955–56 shows a log normal form with a standard deviation of about 100 percent and with one case out of 557 having a value seven times the mean, the young children from Boston and Switzerland more closely approximate a Gaussian-type distribution, with a standard deviation of about 40 percent. Since even these children are not at equilibrium, it is expected that the distribution will become still narrower. For urban populations the distribution at equilibrium may approach a normal Gaussian distribution, but it is expected that the world-wide distribution will always be skewed somewhat toward higher values since, locally, it is possible to increase the amount of strontium-90 per gram of calcium in the soil, and therefore in foods, by factors of 100 to 1000 times the urban mean but to decrease it by factors of only 2 to 10. Present experience in attempting to locate such high values suggests that they will represent a very small fraction of the world population.

From the limited number of samples near equilibrium at any given location it is difficult to estimate the ultimate situation with precision. Nevertheless, it does appear that the bulk of the world's population can be described roughly by a Gaussian distribution with a standard deviation of about 40 percent. Thus, at equilibrium, 99 percent of the people will probably be within about twice, or half of, the mean. Data are simply not available to estimate the distribution in nonurban segments of the population, but it is probably less uniform.

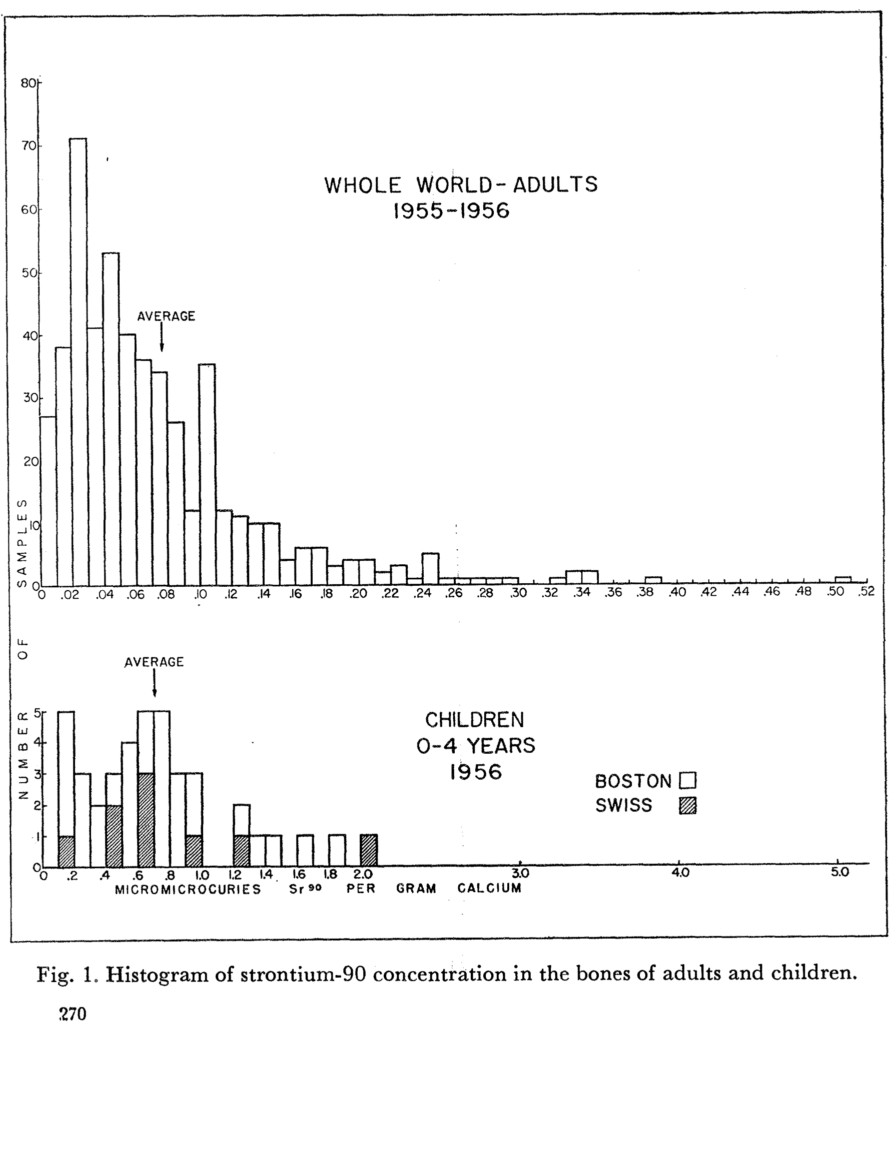

Fig. 1. Histogram of strontium-90 concentration in the bones of adults and children.

Bone Level and Diet

If the amount of strontium-90 per gram of calcium can be defined in the diet of a population group, and if the discrimination factors between diet and bone are known for strontium-to-calcium, the equilibrium level of strontium-90 in the whole skeleton can be predicted. In determining the contribution of strontium-90 to the bone from the diet of any individual it is necessary to know the calcium content, the strontium-90-per-gram-of-calcium ratio for each ingredient, and the strontium-calcium fractionation factors along the food chain. Table 6 gives the relative contribution of calcium by various foods in most national diets (*9*). It is evident that, for a large portion of the world, milk products are the dominant source of calcium. Fish carry very low specific activity of strontum-90, due to the dilution in the large reservoir of ocean calcium. Meat and eggs contribute a negligible amount. Table 7 gives data on the concentration of strontium-90 in milk from various parts of the world, obtained by the New York Operations Office of the U.S. Atomic Energy Commission (*10*) and by the British workers (*11*), for 1956. Table 8 gives new experimental measurements on the concentration of strontium-90 in frozen foods in the United States. Presumably, canned vegetables will show a similar average, but the making of measurements on this important food source is only beginning.

Table 6. Sources of calcium in national diets (in percentage of contribution to total calcium in the diet).

Country	Cereals	Potatoes and starchy roots	Pulses and nuts	Meats	Eggs	Fish	Milk and dairy products
Austria	6	6	1	1	1		85
Belgium–Luxembourg	8	11	1.5	1.5	2	1	75
Denmark	6	9	2	2	1	1	79
Finland	6	7		1	1	1	84
France	8	10	2	2	2	1	75
Germany (West)	7	14	1	1	2	1	74
Greece	17	5	12	1	1	1	63
Ireland	8	12	1	2	2		75
Italy	19	6	8	1	3	1	62
Netherlands	6	7	1	1	1	1	83
Norway	5	5	1	1	1	1	86
Portugal	26	26	9	1	2	6	30
Sweden	4	5	1	1	1	2	87
Switzerland	5	4	2	1	1		87
United Kingdom	6	7	2	2	2	1	81
Yugoslavia	20	6	5	1	1		67
Canada	4	4	2	2	3		85
United States	4	3	2	2	4	1	85
Argentina	9	5	1	3	2		79
Chile	15	7	5	2	2	2	67
Cuba	12	11	10	2	1	1	64
Peru	17	29	8	2	2	1	41
Uruguay	8	5	1	3	2		82
Venezuela	9	5	8	1	1	1	75
India	24	2	2				51
Pakistan	22	1	1				72
Israel	15	3	4	1	3	2	73
Japan	46	17	8		3	8	18
Philippines	39	15	18	2	3	5	18
Egypt	30	2	9	1	1	1	57
Rhodesia	36	2	14	5	1	1	41
Turkey	38	7	14	2	1	1	37
Union So. Africa	21	3	2	2	1	1	71
Australia	7	4	2	3	2		82
New Zealand	5	2	1	2	2	1	88

The data on cereals are also meager as yet, but the indication is that the figures are higher than those for milk of the same region by a factor of about 6 (*12*, *13*). The extent of calcium-strontium discrimination in the transfer from diet to human bone is still debated, although the divergence of opinion has decreased. The previously suggested value of eight (*1*) now appears high. Comar (*14*) has estimated that the factor is about two. However, the work of Spencer, Laszlo, and Brothers (*15*) and of Schulert *et al.* (*6*) suggests a value of about four, and this value has been used in the subsequent calculations.

When one knows the average diet and the strontium-90 content of foods, the relative importance of the various components of the diet can be estimated. In 1956–57 in the northeastern United States, for example, the level in milk was about 3.5 micromicrocuries of strontium-90 per gram of calcium, the vegetable intake was about 7.3 (Table 8), and the level for cereals was estimated at about 20. Therefore, the equilibrium concentration of strontium-90 in the bone for this dietary composition, when the discrimination factor of four and the data of Table 6 are used, is computed to be 1.1 micromicrocurie of strontium-90 per gram of calcium which is dominated by the milk level.

From the diet data and the discrimination factor, the strontium-90/calcium ratio which will occur in the newly deposited bone of children can be calculated. Langham and Anderson (*16*) first suggested this approach and used it to compute the fraction of equilibrium for skeletons of any given age group. The data for bone indicate that for adults the total integrated exchange and remodeling amount to about 7 percent of the equilibrium value if the discrimination factor of four is assumed. In predicting the strontium-90 level in children it is assumed that, in addition to growth, they have the same percentage of exchange and remodeling as adults. Other assumptions and data on which the calculation is based are as follows: (i) The New York milk levels are taken from Table 5 and are assumed to be representative of the northeastern United States. (ii) The relative contribution to the calcium content of the diet from milk and vegetation for this period is given in Table 6. (iii) The yearly accretion of skeletal calcium in males is given by Mitchell *et al.* (*17*). (iv) The discrimination between strontium and calcium in transfer from diet to bone is four. (v) The fetal protective factor is two (*18*).

The calculation yields the solid curve shown in Fig. 2. The dotted curve is computed in an identical manner, but a discrimination factor from food to bone of two instead of four is assumed. Also plotted are the experimental data from the United States and Europe, which closely approximate the theoretical curve for a discrimination of four.

The concentration of strontium-90 in adults suggests that only 1 to 2 percent of bone is exchanged or remodeled per year.

On the basis of these relationships, the equilibrium levels in human bones are computed for the end of 1956 for all continents. The results are given in Table 9. It is clear that the equilibrium level for the Southern Hemisphere will be about one-half that for the Northern Hemisphere.

Future Levels

The concentration of strontium-90 in human bone at any future time for any specified kind and amount of testing can now be predicted within certain limits. The greatest area of uncertainty is that which pertains to the stratospheric reservoir. Although there are a number of ways of attacking this problem, we will start with the actual levels in bone. The

Table 7. Strontium-90 in milk at various locations, 1956. [Data from New York Operations Office and British workers (*10*, *11*).]

Location	Amount ($\mu\mu c$ Sr^{90}/g Ca)
Perry, N.Y.	3.3
State College, Miss.	5.3
Columbus, Wis.	3.4
Mandan, N.D.	8.8
Portland, Ore.	5.5
Japan	2.8
United Kingdom	4.5
Somerset, England	4.2
Other areas in England	6.9

results are summarized in Table 10, along with other comparative data.

There may be as much as a half-year lag between fallout and its effect on the strontium-90 level in vegetation, but this interval is short when compared with the other factors involved; so it will be assumed that diet level and integrated total fallout level are essentially in equilibrium. The predicted equilibrium value for the average population (1.1 micromicrocuries of strontium-90 per gram of calcium in North America), calculated on the basis of fallout through the end of 1956 and on the correlation of the actual bone data with the predicted population levels as a function of age shown in Fig. 2, appears to be fairly well defined. (Actually, if no more strontium-90 were deposited on the ground after 1956, this hypothetical equilibrium level would not be attained, since the concentration of strontium-90 in the reservoir would be reduced continuously by radioactive decay.)

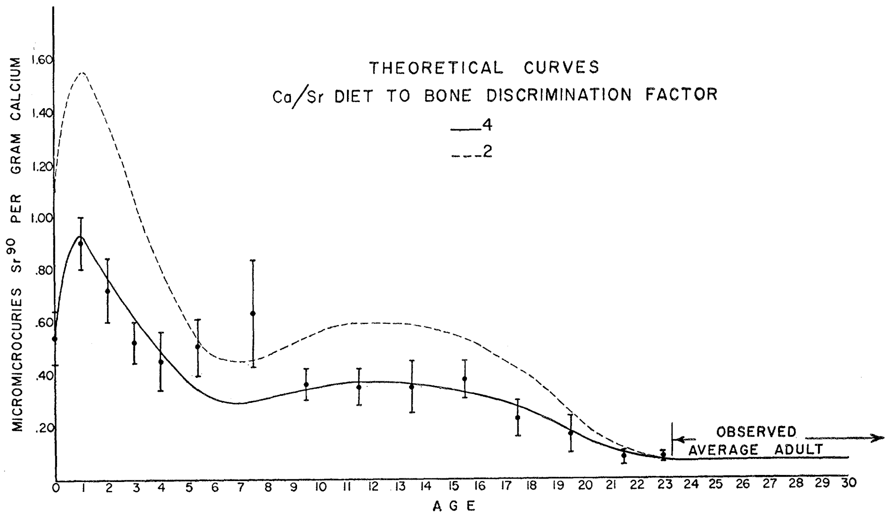

Fig. 2. Comparison of the experimental data on the concentration of strontium-90 in man as a function of age with the theoretical curves obtained from the dietary level of the northeastern United States from 1952 to 1957 and discrimination factors between diet and skeleton of four and two.

Table 8. Concentration of strontium-90 per gram of calcium in common frozen vegetables (1956) (Lamont Geological Observatory data).

Date of harvest	Vegetable	State	Concentration ($\mu\mu c$ Sr^{90}/g Ca)
Sept. 1955	Lima beans	Idaho	6.3 ± 0.3
Sept. 1955	Lima beans	California	10.0 ± 0.4
Early 1956	Lima beans	Delaware	2.9 ± 0.2
Early 1956	Cauliflower	?	2.7 ± 0.3
1955–56	Corn	?	3.6 ± 0.2
1955–56	Peas	?	1.3 ± 0.3
Early 1956	Spinach	Tennessee	6.1 ± 0.1
Feb. 1956	Turnip greens	Tennessee	7.8 ± 0.1
June 1956	Asparagus	Maryland	1.7 ± 0.2
June 1956	Peas	Minnesota	5.8 ± 0.2
July 1956	Peas	Washington	7.8 ± 0.3
Aug. 1956	Peas	Maine	21.3 ± 0.6
Aug. 1956	Cut green beans	New York	20.2 ± 0.5
Sept. 1956	Corn	Minnesota	1.6 ± 0.3
Sept. 1956	Squash	Oregon	3.1 ± 0.2
Sept. 1956	Brussels sprouts	California	4.3 ± 0.2
Sept. 1956	Cut green beans	Pennsylvania	4.6 ± 0.3
Sept. 1956	Cut green beans	Pennsylvania	8.0 ± 0.4
Sept. 1956	Lima beans	Delaware	8.4 ± 0.2
Fall 1956	Cauliflower	New York	8.1 ± 0.3
Fall 1956	Spinach	California	11.5 ± 0.3
Oct. 1956	Asparagus	Maryland	1.7 ± 0.2
Oct. 1956	Broccoli	Maryland	4.7 ± 0.1
Oct. 1956	Broccoli	Maryland	6.7 ± 0.3
Oct. 1956	Broccoli	Maryland	8.5 ± 0.3
Oct. 1956	Brussels sprouts	California	12.0 ± 0.3
Oct. 1956	Cauliflower	New York	9.1 ± 1.3
Mar. 1957	Spinach	California	13.9 ± 0.2
		Average	7.3

Prediction of future levels involves knowledge of the stratospheric reservoir. Libby (*19*) has estimated the mean residence time of the stratospheric debris to be about ten years, with an uncertainty of about 25 percent. A maximum value for the stratospheric debris which will fall out with no further testing could be obtained by multiplying the 1956–57 annual fallout by ten (that is, about 110 millicuries per square mile in northeastern United States). This, however, requires the assumption that all 1956–57 fallout was stratospheric. The limited data on the ratio of strontium-89 to strontium-90 (*20*) suggest that the 1956–57 fallout was largely stratospheric in origin. A minimum estimate can be made by accepting Libby's (*19*) estimate of a current stratospheric burden of a fission equivalent of 24 megatons of TNT and by assuming that this will be deposited uniformly over the entire world. This would add 12 millicuries of stratospheric debris per square mile to the surface of the earth. Machta (*21*) has given valid reasons to support the theory of nonuniform deposition of stratospheric debris. His estimates, made on this basis, would lead to a prediction of 60 to 70 millicuries of stratospheric fallout per square mile in the northeastern United States if there should be no further testing.

It is now possible to predict the level of strontium-90 in children's bones in the northeastern United States for 1977 (when most of the stratospheric debris will have fallen out) if it is assumed (i) that no additional debris is introduced into the stratosphere after mid-1957; (ii) that the fallout to mid-1957 is 26 millicuries per square mile, calculated on the basis of Lamont analyses of 18 soil samples taken in the New York City area; and (iii) that the minimum, probable, and maximum estimates for the stratospheric fallout are 12, 65, and 110 millicuries per square mile, respectively. The equilibrium levels of strontium-90 per gram of calcium will be 1.2, 2.9, and 4.3 micromicrocuries of strontium-90 per gram of calcium, respectively.

These data can be calculated for any other geographical location if the level in the soil at mid-1957 is known. At all times the average for North America would be the highest for any land mass,

Table 9. Equilibrium strontium-90 concentration for end-of-1956 diet (discrimination factor 4).

Continent	Concentration ($\mu\mu c\ Sr^{90}/g\ Ca$)
North America	1.1
Europe	0.9
Asia	1.1
South America	0.5
Africa	0.5
Australia	0.5

with the possible exception of the U.S.S.R., and it would in general be higher by a factor of two than that for countries in the Southern Hemisphere (Table 9).

If testing continues at such a rate that the annual deposit of strontium-90 is 10 millicuries per square mile (as it was for the northeastern United States in 1956–57), the equilibrium level on the ground would be 400 millicuries per square mile, since the mean life of strontium-90 is 40 years. The corresponding equilibrium bone level of the population would reach 21 micromicrocuries of strontium-90 per gram of calcium by the year A.D. 2100.

Conclusions

1) For any given station, the strontium-90 content of adult bone is independent of age.

2) The regional differences in the strontium-90 levels in human bone are much smaller than the differences in total fallout. The maximum difference appears to be a factor of two between United States–Europe and the Southern Hemisphere.

3) The average concentration of strontium-90 in the skeleton for most of the world population at the end of 1956 was about 0.20 micromicrocuries of strontium-90 per gram of calcium. The average for North American or European children was about 0.7 micromicrocuries of strontium-90 per gram of calcium, whereas that for adults was lower by a factor of approximately ten.

4) Single bones can be used for estimating the total skeleton concentration of strontium-90 with a precision of about ± 25 percent. The strontium-90 is reproducibly but inhomogeneously distributed in the adult skeleton, but it appears to be more nearly uniform up to the age of about 19.

5) Increase in the strontium-90 content of the diet follows that of the total integrated fallout, but the strontium-90 level in bones lags behind, due to delay in reaching equilibrium.

6) The present distribution of strontium-90 in adult populations is considerably wider than will be the case at equilibrium. It is estimated that, at equilibrium, the urban populations of the world, including those dependent on central food distribution systems (this will represent 80 percent of the people) will be described roughly by a Gaussian distribution with a standard deviation of about ± 40 percent of the mean.

7) The way in which the high values will be distributed is not yet known, but maximum values are expected in areas where the soil has a low calcium content and where local consumption of milk or vegetable foods is low.

8) The predicted levels of strontium-90 concentration for various age groups in present populations, based on known present diet levels and bone growth, agree well with observed values if a discrimination factor between diet and bone of about four is assumed.

9) If there were no further atomic tests after mid-1957, children in the northeastern United States would reach a peak level of 2.9 micromicrocuries of strontium-90 per gram of calcium. The uncertainty in this prediction probably does not exceed a factor of two.

10) If testing continues at a rate such that a certain region receives ten millicuries per square mile per year, (as the northeastern United States did in 1956–57), the equilibrium bone level for the population will be 21 micromicrocuries of strontium-90 per gram of calcium.

Table 10. Present and predicted future levels of strontium-90.

Situation or condition	Level ($\mu\mu c\ Sr^{90}/g\ Ca$)
Industrial MPC.*	1000
Large-population MPC.	100
Average background radiation equivalent [Libby (*22*)]	50
End of 1956	
World average	0.20
North American children (0 to 4 yr), average	0.67
North American adults, average	0.07
Predicted equilibrium value, North America	1.1
Predicted equilibrium value, Southern Hemisphere	0.5
Future	
Predicted average for children in northeastern United States, 1977 (no further testing—essentially at equilibrium)	
Minimum	1.2
Probable	2.9
Maximum	4.3
Predicted average for population at equilibrium for an area of continuous fallout of 10 mc/mi^2 yr (A.D. 2100)	21

* Maximum permissible concentration recommended by the International Committee on Radiation Protection.

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Frederick George Novy, Pioneer Bacteriologist

On 8 August death ended the long and brilliant career of F. G. Novy (1864–1957). He was one of the early pioneers in bacteriology in this country, having presented the first laboratory instruction in this field in the United States for medical students. This course was given shortly after Dr. Novy and Victor Vaughn returned from a period of study in Koch's laboratory, in 1888.

Novy's research began with chemical studies on cocaine derivatives, which were made as part of his doctoral program in chemistry at the University of Michigan. He then transferred to the Medical School, earned the M.D. degree, and continued on under Vaughn in physiological chemistry. With Vaughn he spent some time studying toxic products of bacteria, "ptomaines." In so doing the two men pioneered in the mass production of pathogenic bacteria. Novy's subsequent studies were more significant and included the differentiation of the relapsing fever spirochetes, study of anaerobes (including the discovery of *Clostridium novyii*), and an investigation of the spirochetes and trypanosomes of birds. A controversy with Shaudinn, who, with Hoffmann, discovered the cause of syphilis, resulted from the latter study. Shaudinn, just before the discovery of the cause of syphilis, suggested a theory, "alternation of generation," to account for the finding of spirochetes or trypanosomes in the blood of birds, depending on when the blood was taken. Novy challenged this observation and correctly so. On the other hand, he quickly accepted the report of Shaudinn and Hoffmann on the etiology of syphilis and congratulated them. Shaudinn accepted the congratulations by letter but remained miffed at Novy's reluctance to accept his "more important" finding of the "alternation of generation" in birds!

In 1909 Novy discovered a virus infecting rats. After some 10 years of work this virus was apparently lost but was then recovered, in 1951, from specimens that had been sealed since 1914–1918. Novy (at this time, age 87) published the results of his earlier studies for the first time, since the virus was again available. The Novy rat virus was the 14th animal virus to be discovered. The course of events in this work illustrates Novy's policy of not rushing into print.

His research also included studies on anaphylotoxin, forerunners of our current concepts of histamine and other substances with marked physiological actions in sensitization reactions. From this work developed another group of observations, on the "primary toxicity of serum," in which he followed the treatment of normal serum with colloidal substances and microorganisms. From current studies one might anticipate that these early observations on primary toxicity of serum will someday have a bearing on the cause of the signs and symptoms of disease and death in infections.

Finally, Novy spent the last years of his active research career on the metabolism of microorganisms, particularly the tubercle bacillus. The techniques developed for the study of the gas exchange and oxygen requirements of microorganisms during growth have since given way to the now widely used Warburg procedures. However, Novy was a pioneer in the field of gas exchange during microbial metabolism.

Many honors came to Dr. Novy in recognition of his professional accomplishments as an investigator and teacher. He received honorary LL.D. degrees from the University of Cincinnati, in 1920, and the University of Michigan, in 1936. He was named Chevalier, Legion d'Honneur (France) in 1924, was awarded the Order of the White Lion (Czechoslovakia) and a Testimonial of the Michigan Legislature, in 1931, and received the award of the 250,000th microscope from Bausch and Lomb Optical Company at the meeting of the American Association for the Advancement of Science in Rochester, New York, in 1936.

Dr. Novy was a charter member of the Society of American Bacteriologists and was the fifth president of the society, in 1904. At the time of his death he was an emeritus member of the National Academy of Sciences.

There remains in the minds of those who were fortunate enough to attend Dr. Novy's classes a vivid memory of a man who, above all, was a clear thinker. He was stern yet kind, strict but tolerant, a demanding taskmaster with a keen sense of humor. His influence will continue to shape the decisions of his students and, in turn, of their students for years to come.

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