

down by the larger particles. It consists largely of matter drawn up into the fireball from the surface which is either totally or partially vaporized. Under these conditions so much matter is vaporized by virtue of the fireball's touching the ground that the particle sizes formed in the freshly cooled vapor are large.

The second and third types of radioactive fallout are world-wide in nature and consist of finer material and are divided according to whether the material happens to lie in the lower part of the atmosphere, the troposphere, where rain and weather phenomena occur, or the higher part of the atmosphere, the stratosphere, which is free of such precipitating mechanisms. The tropospheric fallout occurs in a matter of two or three weeks or a month or so. It occurs largely as a result of rain and snow, and water precipitation in general, and falls in the general latitude of the test site. The stratospheric fallout, in contrast, takes years. We are not completely certain, but it appears that an average time of something like ten years, or perhaps somewhat less, is a reasonable figure, and during this time the distribution becomes nearly world-wide. When the stratospheric fallout manages finally to pass into the troposphere it is quickly removed by the same type of mechanism that brings down the world-wide tropospheric fallout, namely rain and moisture.

The precipitating mechanisms consist in general of the collision of the tiny particles with moisture droplets in clouds, together with the interception of particles by falling raindrops. The first mechanism was recently suggested by Dr. Greenfield in connection with Sunshine problems--the study of world-wide fallout is called Project Sunshine. In addition to the scavenging action of rains and fogs, there is definite evidence for a considerable probability of pick-up on direct contact of air with surfaces such as the leaves of grass and trees. Frequently, grasses are found to have higher strontium-90 content than would correspond to the soils in which they grow, and this is due undoubtedly to direct pick-up.

The dissemination of strontium-90 and all fallout is greatly dependent upon the firing conditions. There is

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due to the slightly higher fission yield. The content of radiocesium in rainwater is comparable to that of strontium-90. Also, the content of radiocesium in the human body as measured by Marinelli at Argonne and Anderson and Bingham at Los Alamos agrees well with the fact that it has an average residence time in the human body of about five months as compared to many years for strontium-90. The radiocesium data are very interesting because of their bearing on the fallout dissemination mechanism and the confidence with which we can establish the probable future behavior of radioactive strontium. The data confirm previous suggestions as to the dissemination mechanism, that is, we find that radiocesium fallout except of the local variety is carried down very largely in the form of moisture droplets and that there is some direct pick-up by leaves and grass on surfaces. It is captured and held tightly by the top two inches of most soils, so the water which falls and runs off in the form of rivers is clean by the time it has drained a short distance through soil. All of this is very similar to the radiostrontium behavior.

The plants pick the strontium-90, and radiocesium to a lesser extent, out of the soil and also off of their leaves and take it into their systems. There appears to be a discrimination mechanism which operates in most plants so that the strontium-90 content of the plant is considerably less relative to its calcium content than in the case of the soil. On the average, the discrimination factor between the top soil and plants against strontium relative to calcium seems to be about 1.4. When the cows eat grass they further discriminate by about a factor of 7 in making milk so there is an over-all protection factor for strontium-90 from the top soil to milk of about 1.4×7 or 10. Also, there is a further discrimination factor against strontium relative to calcium in the human body. This factor is not known too well, but is known definitely to be at least as large as 2 and is thought possibly to be as high as 8. Researches are now in progress to settle this. Therefore, there is a series of protective factors which makes the concentration of radiostrontium derived from milk relative to calcium in human bone not over $1/20$ and possibly as little as $1/80$ of that in the top soil. Of course, it should be pointed out that there is a considerable part of the fallout which is picked up directly on the leaves and to this the factor of 1.4 does not apply,

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so for this fraction of the fallout the protective factor may be reduced to 14. Since milk is the source of most of our calcium, this means that the actual ratio of radiostrontium concentration in new human bones relative to that in the top soil should approach these numbers.

It must be realized that though only a small part of the calcium is derived from vegetables and meat, a similar calculation must be made for this portion and the total average ratio obtained. It seems that the meat-vegetable overall discrimination factor is about 10 so if 20 percent of the calcium is derived from such sources on the average the average overall factor will be between 1/13 and 1/30. The experimental data on new human bone in children appear to give a smaller figure, 1/60, as mentioned later.

A matter of importance in connection with the amount of strontium-90 which one would expect to be deposited in human bone as a result of atomic weapon detonations is the calcium concentration in the top soil. Since calcium is so similar to strontium, it seems very likely, and the evidence confirms this, that high available calcium content of the soil will reduce the probability of strontium-90 being taken up into the plants. Of course this probably does not have nearly as great an effect on the uptake of the material which is picked up directly on the leaves. We might expect therefore that soils which are particularly low in calcium might show higher strontium-90 contents for the grasses grown on them. This is, in fact, so, and sheep and goats and cattle feeding on such pasture display a higher strontium-90 bone content.

How such calcium deficiencies in the soil should affect the strontium-90 uptake by the human population is a most important question. One sees immediately that food distribution systems are such that the food supply is derived from large areas, and that there is consequently a sharp reduction in the sensitivity of the human population to calcium deficiencies in local soils. This is brought out particularly well by the data on the radium contents of human bones and their obvious lack of strong dependence on the radium contents of local waters. But for people who consistently drink milk from cows grazing on such ground there should be a definite effect on the amount of radiostrontium uptake and the effect should be proportional to

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thorium and potassium in the ground and in our surroundings. We know these quantities amount to something like 10 milliroentgens per year for an average person in this latitude. But we also know that there are considerable variations with conditions.

For example, a person living in a brick house may very well get 25 to 50 milliroentgens per year more than one living in a wooden house, because of the natural radioactivity of the bricks. It is also very well known that whereas at sea level in this latitude the cosmic ray dosage is 37 milliroentgens per year, at 5000 feet altitude as in Denver, Colorado, the dosage from cosmic rays is 60 milliroentgens per year, or a difference of 23 milliroentgens per year. What is this in terms of strontium-90 body burden?

First, we must consider what part of the natural radiation, if any, is similar to the radiation of strontium-90 in biological effect so we can say without doubt and hesitancy that the physiological effects, whatever they are, will be the same for the same energy absorbed. Fortunately, the cosmic rays seem to fit this bill. In other words, we are at liberty to compare the cosmic ray radiation dosages with the dosages from radiostrontium in our bone structure. The reason this is permissible is that the ionization density along the tracks of the mu-mesons which are the principal cosmic ray components at sea level and at altitudes of 5000 feet are nearly the same as those of the yttrium-90 beta rays, the principal radiation which radiostrontium emits; that is, radiostrontium has a radioactive daughter, yttrium-90, which emits a very energetic beta ray and the ionization density along the track of this radiation is very similar to that of the mu-mesons of the cosmic rays and their disintegration electrons, and it is generally accepted by health physicists and radiobiologists that radiations of the same ionization density have very similar, if not identical biological effects for the same energy absorbed. The high energy of the yttrium-90 gives it an average distance of penetration in tissue of 2 millimeters so any effect of local non-uniformity of deposition of strontium-90 in the bone is removed. The cosmic ray exposure is, of course, uniform throughout the bone structure. Therefore, we can equate cosmic ray dosage with strontium-90 dosage and thus it is possible for us to say that the

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difference between one altitude and another is equal in effect, other effects being equal, to a certain number of Sunshine Units in bone. Now to follow this thought through, 1 Sunshine Unit is equal to 3 milliroentgens per year. Therefore, the difference in annual cosmic ray radiation dosage between Washington, D. C., or any place at sea level in this latitude, and Denver, Colorado, is equal to 8 Sunshine Units, that is, 16 times the present body burden of equilibrium bone or bone near equilibrium as we see it in young children who are growing now.

Therefore, we must examine whether anything in our experience indicates that these differences are significant in terms of the occurrence of the principal effects expected of radiostrontium, namely leukemia and bone cancer. Now of course when one looks for such vital statistics, one finds that they are very hard to acquire. However, the National Institutes of Health and the Department of Health, Education and Welfare, have given us statistics for the occurrence of leukemia and bone cancer for the year 1947 for the three cities, New Orleans, San Francisco and Denver. They are shown in Table I.

TABLE I
Occurrence of Bone Cancer and Leukemia
(New Cases per Year per 100,000 Population)

	<u>Bone Cancer</u>	<u>Leukemia</u>
Denver	2.4	6.4
New Orleans	2.8	6.9
San Francisco	2.9	10.3

It is clear from this table there is no obvious effect of altitude, and it is also clear that there are other factors which are noticeably more important than cosmic ray dosage. Of course there may still be a considerable effect of altitude hidden in large fluctuations caused by other factors, which presumably are largely unknown and we cannot say that this proves anything. It does, however, give us some assurance from normal experience that the effect of eight Sunshine

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Units will not cause a detectable increase in bone cancer or leukemia.

This fits well with the laboratory data on animals and the limited experience on humans with radium. That is, 1 microcurie being 1000 Sunshine Units, is still considered to be pretty safe on the basis of the laboratory data. It is set as a tolerance for occupational workers and it is therefore reasonable that eight Sunshine Units should give an effect so small as to be very, very difficult to detect. It is, I think, helpful for us, however, to realize that the present body burden of strontium-90 in new bone from the weapons tests that have occurred in the past is equal to the increase in cosmic ray intensity that goes with an increase of some 400 feet in altitude, a very small fraction of the difference in cosmic radiation intensity between Denver and sea level. Therefore, at the same time that we consider the possible effects of strontium-90 from such concentrations, we may deduce from our everyday ordinary experience limits on the effects to be expected. None of the evidence on the occurrence of bone cancer or leukemia as a function of altitude has given us any reason to believe that the present tolerance limits are in any way in error. The present body burdens in new bones are small compared to these limits.

Separate from the strontium-90 effects are the effects of general gamma radiation, the radiation that is received mainly from outside the human body, and which comes mainly from the very young fission products in the local fallout area, but which can come in smallest part from radiocesium accumulating on the ground in the case of the stratospheric fallout, or more importantly, from the shorter-lived fission products deposited by the tropospheric fallout. Of course, weapons tests are so conducted as to avoid exposures to local fallout, so our present discussion of the effects of weapons will be restricted to the much smaller gamma ray doses from the offsite tropospheric and stratospheric types of fallout. In time of war, of course, it would be the local fallout which would be of more direct concern, next to blast and thermal effects, and it is to this aspect of fallout which FCDA addresses itself in the main. In regard to nuclear tests, we have to study the effects on human genetics and the possible effects of such doses of radiation on health.

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chemical in nature. Now if this be so, and the radiation induced mutations are nearly always caused by chemicals which are produced in the first instance by radiation, then chemicals themselves which are not produced by radiation but have other origins, can cause mutations, so it seems likely that a major part of the natural or spontaneous mutations in any species is not radiation induced. This point is an important one to settle, for the reason that we have to compare the effects of fallout radiation with the fraction of the natural spontaneous mutations which is due to the radiation we are normally subjected to. In other words, if the normal mutations are all due to radiation, then the effects of the additional radiation from general test fallout, or from other sources of radiation such as atomic power, or the medical uses of isotopes and X-ray, will be larger. It seems likely, and many genetic authorities agree on genetic grounds with this conclusion, that a major portion of the spontaneous mutations of the human species is not due to radiation but due to other causes. Therefore, a fraction of the spontaneous mutations in the human species is taken as being due to irradiation. Now, what this fraction is, it is difficult to say, but Professor H. J. Muller has estimated that this might be 10 percent. Therefore, one estimates the 150 milliroentgens per year from natural radiation now causes about 10 percent of the spontaneous mutations, and therefore, that the test fallout if continued indefinitely will, at the present level of about 1 to 5 milliroentgens per year, cause an increase in the natural spontaneous mutation rate of something like 1/50 of ten percent, or 0.2 of a percent of the spontaneous mutations. In the extreme, if it should prove that all of the spontaneous mutation rate is radiation induced despite the chemical arguments, the effect would be ten times as great, or two percent. Dr. Dunning of the Division of Biology and Medicine of the AEC estimated 1.4 percent in 1955 on similar assumptions. (The Scientific Monthly 81, 265-December 1955.) This effect is one which is comparable to moving to a slightly different locality and is much less serious than changing from one house to another or doing any of a dozen things. The only important point is that genetic effects show only if large numbers of people are subjected to them. Therefore, we would expect that the effects of large populations changing their environment, such as living at a higher altitude, or living in a region of naturally higher radioactivity, should cause genetic

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one another in general shape and that the magnitude of the distribution of the strontium-90 contents of the Chicago stillborn babies was not in any way anomalous. Therefore, we shall take the distribution curve for radiostrontium to be the same as for the normal strontium data. The occurrence of non-radioactive normal ordinary strontium in the bones should certainly tell us what the equilibrium distribution will be for radioactive strontium, and from it we should be able to learn the points about distribution which we cannot yet learn in any detail from the radioactive strontium itself. Turekian and Kulp noted in their study of normal strontium in human bone that in a given region the deviation from the average was about 34 percent of the average, that is, for human bone from the regions Colorado, Texas, Cologne, Bonn, Venezuela, Chile, Vancouver, China and India. In each instance the ratio of the standard deviation from the mean itself was taken and the average calculated to obtain 34 percent. Therefore, we take 34 percent as the expected standard deviation from the mean for a given locality for the eventual strontium-90 equilibrium burden in human bones.

With this result we can, assuming a normal error curve shape of the distribution of probabilities, answer the immediate question: What is the probability of an individual exceeding the tolerance even though the mean does not? On the basis of this analysis we find that at steady state and in equilibrium the variation from the mean will constitute an error curve with a shape corresponding to the standard deviation, being $1/3$ of the mean. Therefore, at steady state among people living in a given locality, only one person in about 700 will have more than twice the average strontium-90 burden, and the chances of anyone having as much as three times the normal burden will be about one in twenty million.

Now what about the non-equilibrium distribution, when the strontium-90 is finding its way into the biological system? Obviously, the burden will be much lower here, but the deviation from the mean will probably be much higher percentagewise, particularly in adults where most of the bone has been deposited before strontium-90 was produced. The present strontium-90 content of adults depends very much on the growth rate and the metabolic activity of the

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The Northern part of the United States has about 20 to 30 millicuries of strontium-90 per square mile. The Southern States are somewhat lower. The low figure of 7 millicuries per square mile for Grand Junction, Colorado, is probably due to local climatic and sample site conditions.

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Table II

Health and Safety Laboratory 1956 Survey of U. S. Soils for Strontium-90
Samples taken between October 8 and 13, 1956. Strontium extracted with
6N HCl at room temperature. Replicates represent individual soil aliquots
taken after sampling and air drying. Each error term represents a
standard deviation due to counting error.

Sampling Site	Depth	d/m/gm soil	mc/mi ²	mc/mi ²	
				Ave.	Total
Albuquerque, N.M.	0-2"	0.078 ± 0.001	7.5 ± 0.1	7.3	
		0.075 ± 0.001	7.2 ± 0.1		
	2-10½"	0.008 ± 0.002	4.4 ± 0.9	3.4	11
		0.005 ± 0.002	2.4 ± 0.8		
Atlanta, Ga.	0-2"	0.35 ± 0.007	14 ± 0.3	15	
		0.42 ± 0.009	16 ± 0.4		
	2-6"	0.018 ± 0.004	2.8 ± 0.6	3.0	18
		0.021 ± 0.003	3.3 ± 0.5		
Binghamton, N. Y.	0-2"	0.32 ± 0.007	17 ± 0.4	18	
		0.35 ± 0.007	18 ± 0.4		
	2-6"	0.019 ± 0.003	4.4 ± 0.8	4.8	23
		0.023 ± 0.005	5.2 ± 1.1		
Boise, Idaho	0-2"	0.23 ± 0.006	20 ± 0.6	22	
		0.26 ± 0.006	23 ± 0.6		
	2-6"	0.012 ± 0.002	3.1 ± 0.6	3.5	26
		0.015 ± 0.002	4.0 ± 0.6		
Des Moines, Iowa	0-2"	0.31 ± 0.007	23 ± 0.5	23	
		0.31 ± 0.007	23 ± 0.5		
	2-6"	0.028 ± 0.002	7.6 ± 0.7	7.1	30
		0.024 ± 0.003	6.6 ± 0.7		
Detroit, Michigan	0-2"	0.26 ± 0.006	20 ± 0.5	20	
		0.27 ± 0.006	20 ± 0.5		
	2-6"	0.038 ± 0.003	7.3 ± 0.5	7.8	28
		0.044 ± 0.003	8.4 ± 0.6		
Grand Junction, Colo.	0-2"	0.10 ± 0.001	7.8 ± 0.1	7.0	
		0.091 ± 0.001	7.1 ± 0.1		
		0.11 ± 0.019	8.2 ± 1.4		
		0.070 ± 0.013	5.1 ± 1.0		
	2-10½"	≤ 0.002	≤ 0.45	≤ 0.48	7
		≤ 0.002	≤ 0.51		

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H E H K I H L H I L A I A E K Y A E E E

Sampling Site	Depth	d/m/gm soil	mc/mi ²	mc/mi ²	
				Ave.	Total
Jacksonville, Fla.	0-2"	0.11 ± 0.009	7.3 ± 0.6	7.3	
	2-6"	0.013 ± 0.004	2.7 ± 0.9	3.4	11
		0.020 ± 0.005	4.0 ± 1.0		
Los Angeles, Calif.	0-2"	0.12 ± 0.008	6.9 ± 0.5	7.5	
		0.14 ± 0.009	8.0 ± 0.5		
	2-7"	0.009 ± 0.002	3.3 ± 0.9	2.8	10
		0.006 ± 0.002	2.2 ± 0.7		
Memphis, Tenn.	0-2"	0.27 ± 0.006	15 ± 0.4	15	
		0.26 ± 0.006	15 ± 0.4		
	2-6"	0.028 ± 0.003	6.5 ± 0.7	6.6	22
		0.029 ± 0.003	6.6 ± 0.7		
New Orleans, La.	0-2"	0.24 ± 0.006	8.8 ± 0.2	8.6	
		0.22 ± 0.006	8.3 ± 0.2		
	2-6"	0.009 ± 0.002	3.3 ± 0.9	2.8	11
		0.006 ± 0.002	2.2 ± 0.7		
New York, New York	0-2"	0.21 ± 0.006	10 ± 0.3	12	
		0.29 ± 0.007	14 ± 0.3		
	2-6"	0.072 ± 0.004	14 ± 0.8	14	26
		0.068 ± 0.004	14 ± 0.8		
Philadelphia, Pa.	0-2"	0.17 ± 0.005	12 ± 0.4	12	
		0.16 ± 0.005	11 ± 0.4		
	2-6"	0.029 ± 0.003	7.3 ± 0.8	6.8	19
		0.026 ± 0.003	6.4 ± 0.7		
Rapid City, S. D.	0-2"	0.29 ± 0.006	20 ± 0.4	22	
		0.34 ± 0.006	23 ± 0.4		
	2-6"	0.053 ± 0.004	12 ± 1.0	11	33
		0.045 ± 0.003	10 ± 0.7		
Rochester, N. Y.	0-2"	0.22 ± 0.006	16 ± 0.4	16	
	2-6"	0.013 ± 0.004	2.5 ± 0.4	2.5	19
		0.013 ± 0.002	2.5 ± 0.4		
Salt Lake City, Utah	0-2"	0.32 ± 0.007	22 ± 0.5	22	
		0.33 ± 0.007	23 ± 0.5		
		0.31 ± 0.007	22 ± 0.5		
	2-8"	0.016 ± 0.002	5.7 ± 0.7	5.8	28
		0.016 ± 0.002	5.9 ± 0.8		
Seattle, Washington	0-2"	0.46 ± 0.011	17 ± 0.4	17	
		0.44 ± 0.010	16 ± 0.4		
	2-6"	0.051 ± 0.007	9.4 ± 1.2	9.5	27
		0.052 ± 0.004	9.6 ± 0.7		

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L E R I H L L X L L L E P L L L

The differential rates at which the fallout has been occurring probably are best measured by the so-called "pot collection" method. A bucket with vertical walls of appreciable height is placed out in the open and allowed to collect the total fallout for a given period including the rain, snow, dust, etc. The bucket is left out whether it has rained or not and covers the total fallout for a given period. Figures 6 and 7 give the curves so obtained for New York and Pittsburgh areas together with the estimated errors of measurement. It is interesting to note the changes in slope and to correlate them with the occurrence of test activities and the relatively short-lived tropospheric fallout. The minimum slopes which appear during quiet periods when no one is testing are the stratospheric fallout of which we have spoken and these slopes when we have enough pots operating all over the world will, when taken together with the results of the measurements of the amounts of radiostrontium and radiocesium in the stratosphere, give an accurate value for the stratospheric residence time and settle the mixing question.

In addition to the intensity of fallout, the question of the fraction of the radiostrontium, and, for tropospheric fallout, the radioiodine of eight-day half-life, that is in assimilable form is an important one. So far most fallout strontium appears to be completely water soluble and therefore most assimilable, though continued tests on this point should be made. Direct leaf pick-up of course promotes assimilation of the strontium because the plant differentiation against strontium when it assimilates it from soil thus is avoided. Another factor is, of course, the concentration of available calcium in the soil. By available calcium we mean calcium which is available to plants and not the total calcium in the soil. It is known that soils which are high in available calcium produce plants of lower radioactive strontium content; that is, the radioactive strontium to calcium ratio in the plant is lower as a direct consequence of the lower concentration of radiostrontium in the available soil calcium. In addition, as mentioned previously, plants tend to prefer calcium to strontium with a discrimination factor of about 1.4. Sheep which grow in certain areas of Wales have shown concentrations in their bones approaching 150 Sunshine Units, while sheep and cattle growing in the U. S. have hardly ever exceeded one-fifth of this. The Welsh soil in certain areas

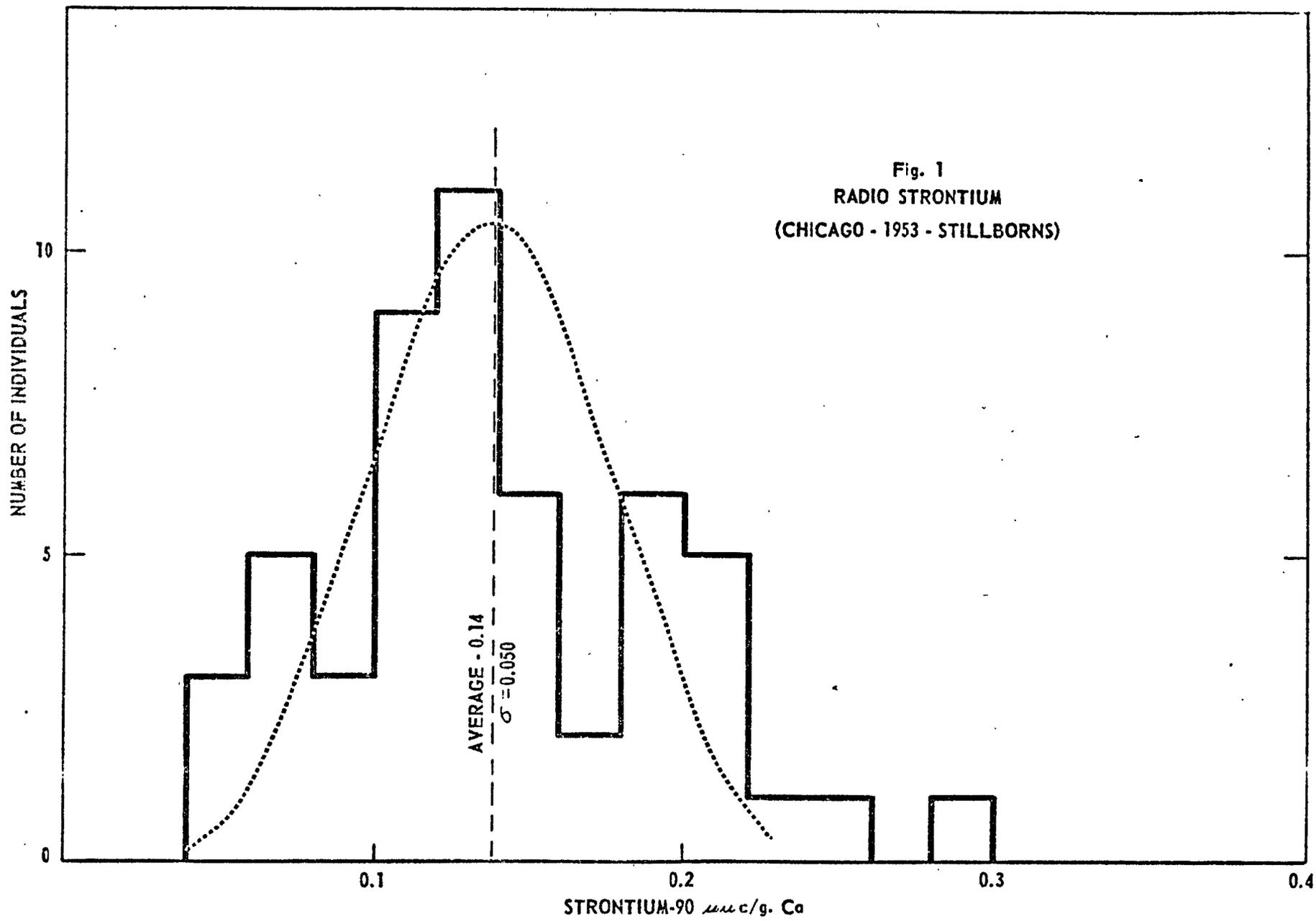
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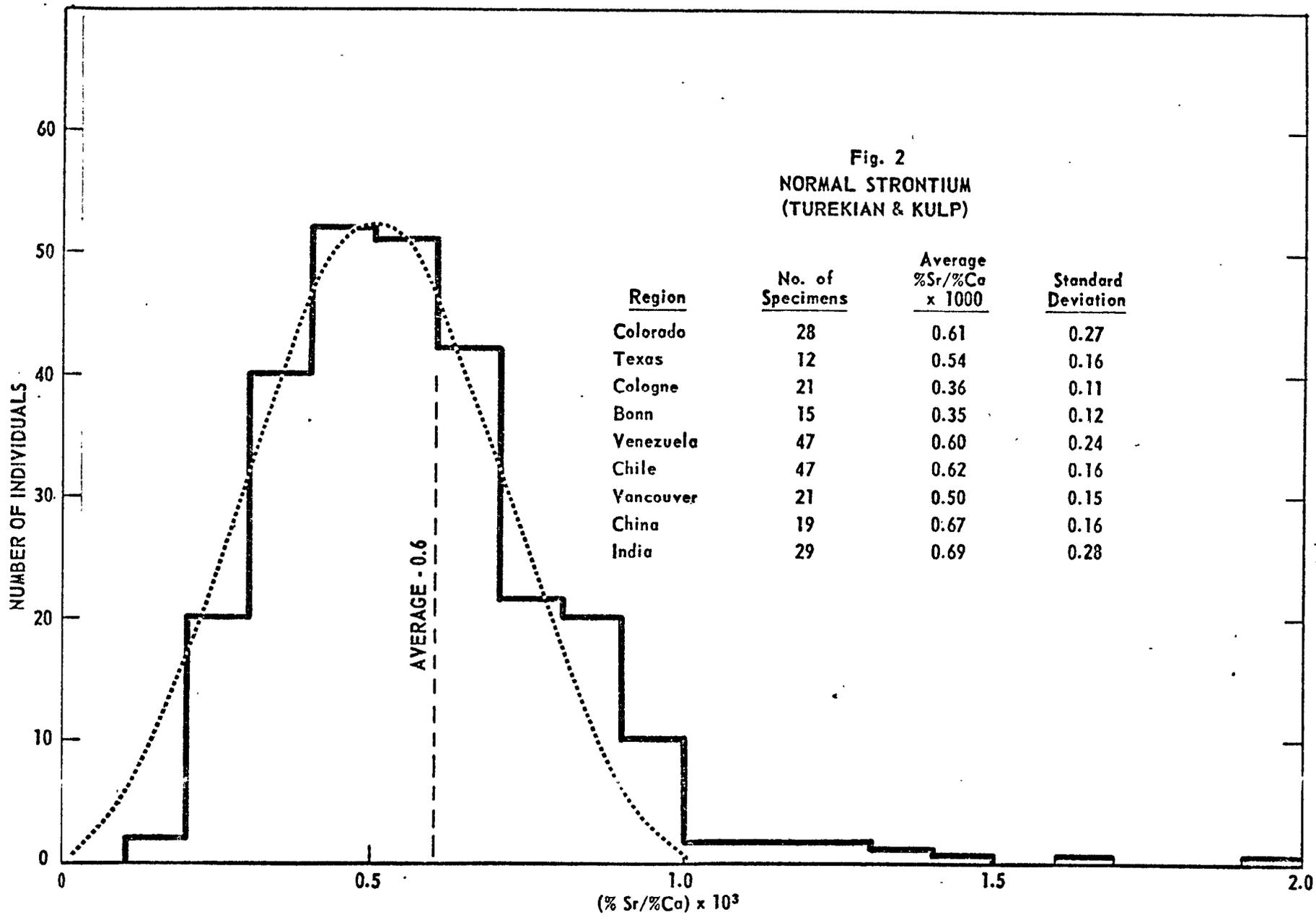
equilibrium concentration of human bones if testing continued indefinitely at the average rate of the past five years. This level would be approached only after a few decades. After 28 years the level would be half of this equilibrium value, and after another 28 years, 56 years total, from an arbitrary beginning which we have set as 1952, we would expect in the year 2008 three-fourths of the equilibrium figures. So somewhere between 4 and 15 Sunshine Units of strontium-90 in human bones in the United States might result from the present type of testing being continued for the next 50 years.

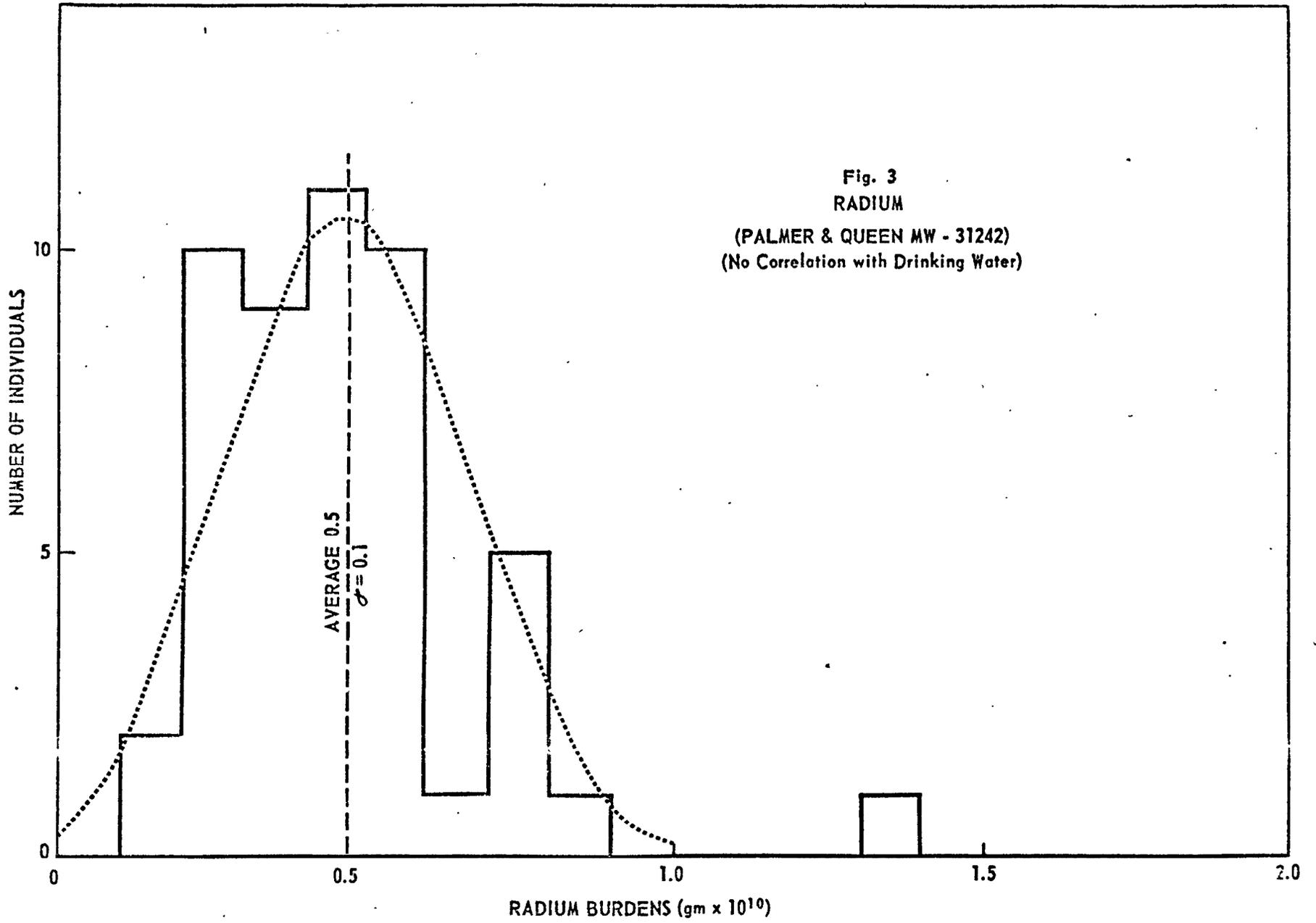
In those certain areas in the world where the soil is low in calcium, this level might go five-fold higher. At the present rate of testing we might indeed approach the figure of 100 Sunshine Units, the tolerance limit for large populations, at the beginning of the 21st century for these certain limited regions in the world. The observed conditions in these regions could be relieved, however, by fertilization of the soil with calcium, either calcium nitrate or lime being used, as appropriate from other considerations.

The Sunshine Project continues to study the problems of world-wide fallout--the stratospheric inventory of radiostrontium and radiocesium, the occurrence of these isotopes in the soils and water and the biosphere all over the earth, the biological effects at certain levels of contamination with strontium-90, and to a lesser degree with cesium-137, and the possible genetic effects of the low gamma ray dosages associated with world-wide fallout from atomic tests. All of these are studied not only with the point in mind of devising methods of protection against atomic warfare, but also with the thought of possible application in the remote event of industrial accidents which may happen in connection with certain of the peaceful uses of atomic energy, particularly atomic power. Certainly an understanding of the basic principles of world-wide fallout is applicable to the control and safe-handling of isotopes. All of this is done in collaboration with the United Nations Scientific Committee on the Effects of Atomic Radiation, and it is to be hoped that as the data appear all of the countries in the world will join together in this international effort to understand better the effects of the great new fact in life, the nuclear atom.









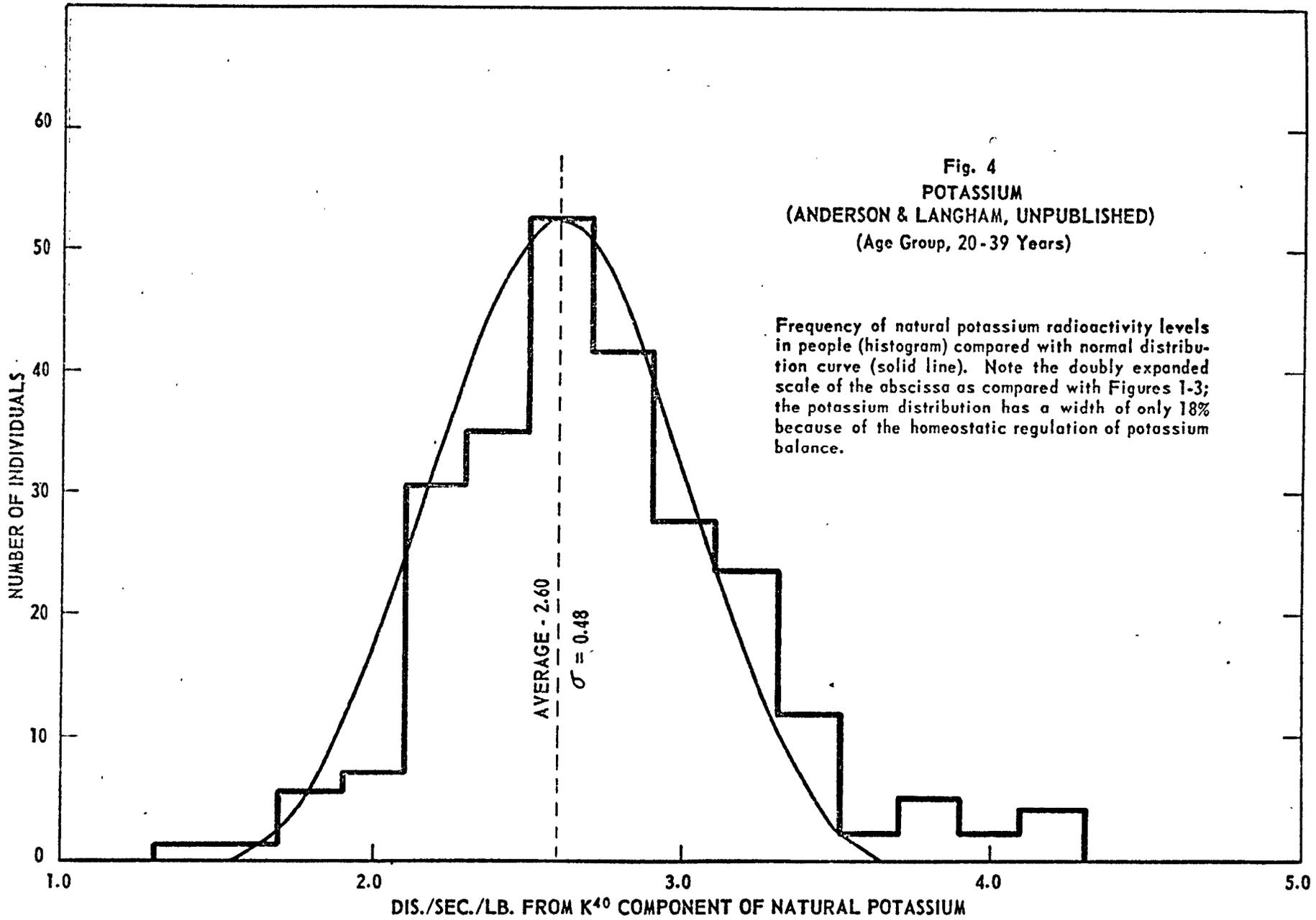


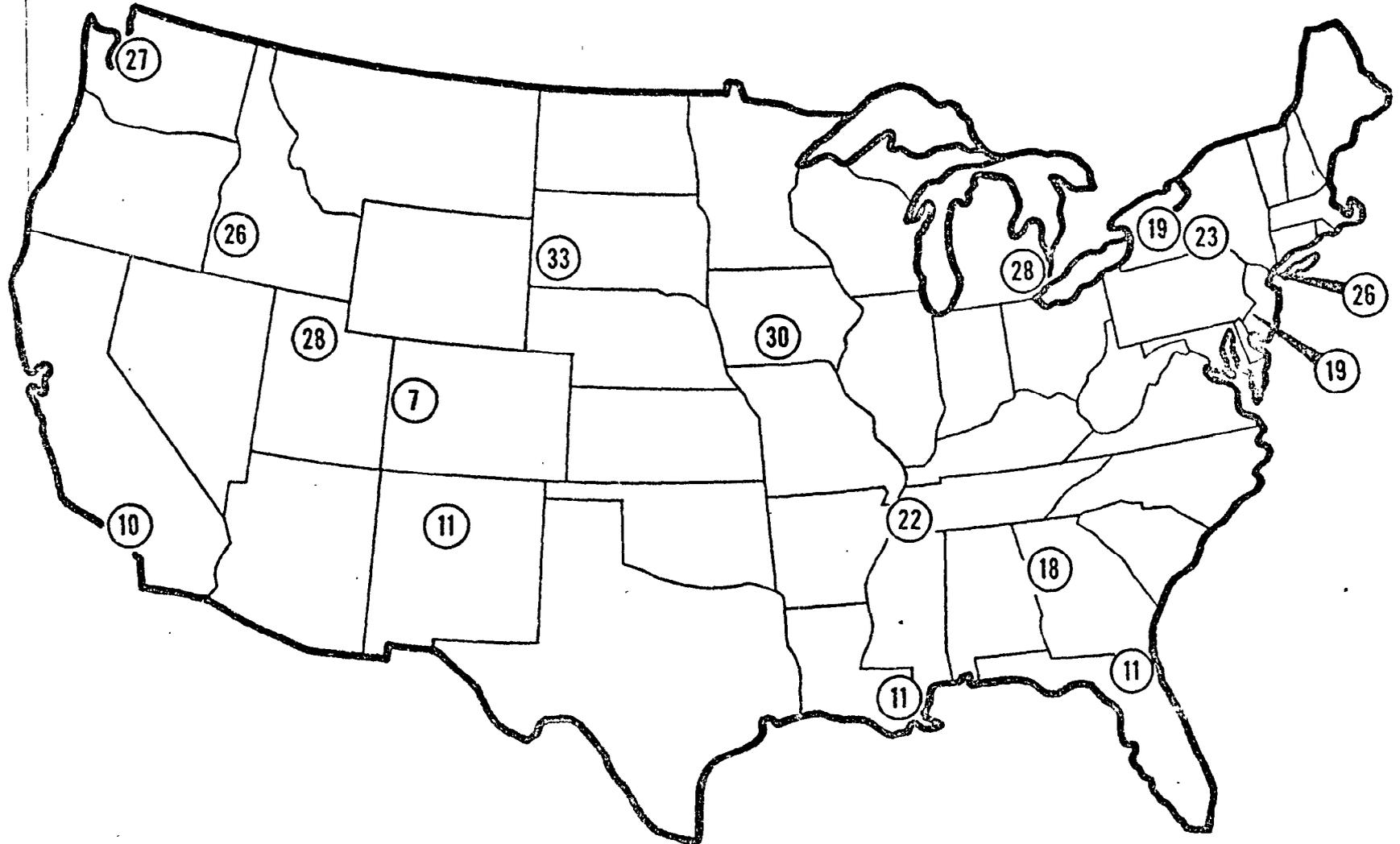
Fig. 4
POTASSIUM
 (ANDERSON & LANGHAM, UNPUBLISHED)
 (Age Group, 20-39 Years)

Frequency of natural potassium radioactivity levels in people (histogram) compared with normal distribution curve (solid line). Note the doubly expanded scale of the abscissa as compared with Figures 1-3; the potassium distribution has a width of only 18% because of the homeostatic regulation of potassium balance.

AVERAGE - 2.60
 $\sigma = 0.48$

Fig. 5

Sr^{90} IN U. S. SOIL (HASL - OCT. 8, 1956) (HCl EXTRACTION METHOD)



Numbers are in mc/mi^2 at individual site.

