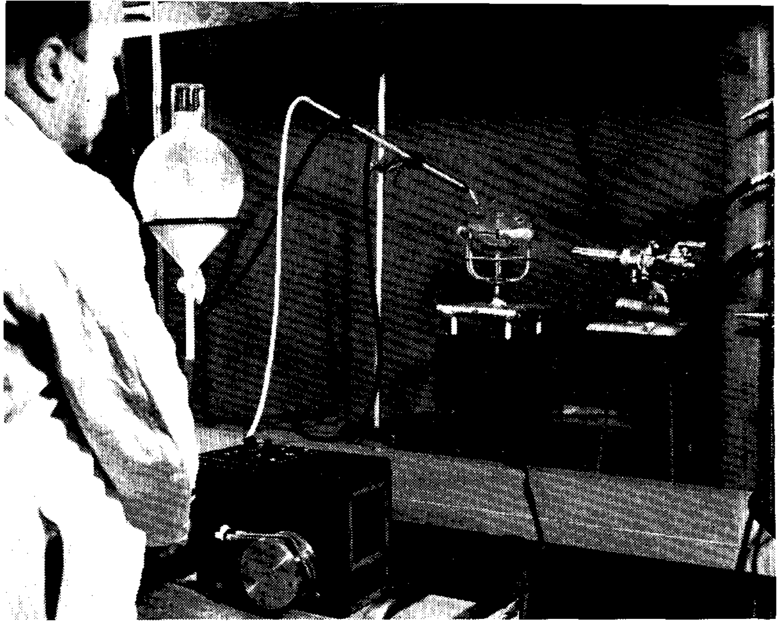


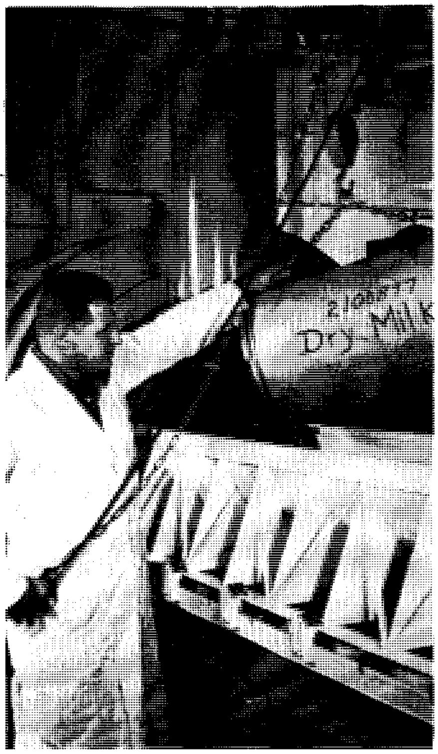
Rapid ashing technique is used to prepare milk samples for radioactivity tests at Taft Sanitary Engineering Center

Technician at AEC's Health and Safety Laboratory inserts strontium-90 samples into low-level, anticoincidence counter

Strontium-90 in Food

J. L. KULP, R. SLAKTER, and A. R. SCHULERT, Lamont Geological Observatory, Columbia University, Palisades, N. Y.

Weekly milk sample is placed in radioactivity counter at Los Alamos



STRONTIUM-90 has become a common term in the general public's vocabulary in the few years since the truly world-wide nature of nuclear fallout was made clear in early 1955. It has become increasingly common in very recent months. As numerous newspaper articles have pointed out, radioactive debris in general, and strontium-90 in particular, is now dispersed throughout the world as a result of nuclear bomb testing. This debris is probably present in measurable quantities on every square foot of soil on earth. It is present in our foods so that we probably ingest some at every meal. Nuclear fallout therefore represents a problem of universal interest and concern.

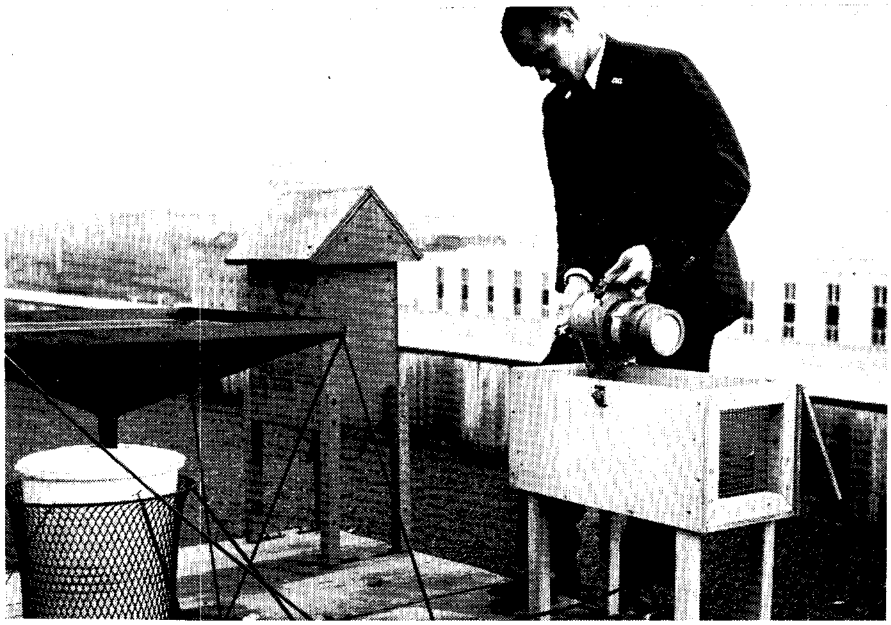
Three main facets of this problem will be considered here. The first involves the physical aspects of fallout, including the manner in which the debris produced at detonation is transmitted through the atmosphere to the soil, plants, foodstuffs, and man. The second deals in detail with the particular aspects which relate to food. The third is a question of the magnitude of the danger which strontium-90 represents.

Broad Physical Factors

Whereas strontium-90 is the most hazardous bomb-produced isotope from the standpoint of possible direct damage to the human body, it is only one of many produced in nuclear bombs. In Table I the fission-produced radioisotopes are classified according to half life. Of the 189 produced, more than two-thirds (131) have half lives of less than one day and thus present no long range hazard in relation to weapons testing. Another 26 with half lives ranging from one day to one month are also of lesser importance, although iodine-131 (half life 8 days) has been measured in human thyroid, and barium-140 (half life 12 days) has been found in milk. At the other end of the scale, the ten which have half lives of greater than 10^4 years are not a current problem in view of the low specific activity concomitant with their long half lives, although one such isotope, carbon-14, has recently attracted attention because of its possible long-term genetic effects over many generations.

Thus attention is centered on the 22 isotopes which have half lives ranging from one month to 100 years. When other factors are considered, principally the matter of gastrointestinal absorption, attention is focused on strontium-90 and cesium-137 as the two most potent hazards.

Strontium is chemically similar to calcium, and strontium-90 lodges in the bone where it resides for long periods of time. Since its concentration in soft tissue is comparatively very small, and since strontium-90 as well as its radioactive yttrium daughter emits only the short range beta rays, the gonads are not irradiated appreci-



Station on roof of Municipal Building in downtown Washington, D. C., samples air, rain, and snow for measuring radioactivity of fallout

ably by these isotopes; hence strontium-90 is primarily a somatic or direct body hazard rather than a genetic hazard. Cesium-137, on the other hand, is more uniformly distributed throughout the body and is considered to be the principal genetic hazard.

Radioactive bomb debris is classified in three categories: local, tropospheric, and stratospheric. Local debris falls out in the immediate vicinity of the bomb explosion. Tropospheric is more widely dispersed into the atmosphere, but does not penetrate the tropopause which exists at about 40,000 feet. This debris has an average residence time in the atmosphere of about one month; it comes down with the rain. Thus it has time to be distributed around the world longitudinally (in bands) through the prevailing westerly winds. It does not have time, however, to become widely distributed latitudinally. Stratospheric debris penetrates the tropopause and, being above the weather, filters down very slowly. The average residence time in the stratosphere is not actually known, but is estimated to be about three years.

Figure 1 shows the average measured fallout of strontium-90 in millicuries per square mile in the various latitude bands. The high value in the north temperate zone reflects the facts that most bomb tests have been carried out in this latitude and that tropospheric debris stays largely within a given band. Presumably the stratospheric debris can spread uniformly over the whole globe, but whether or not it falls out uniformly is open to question. It has been suggested that because of meteorological phenomena greater amounts would come out in the temperate zones. Note that the high fallout band is also the high population band. Furthermore, certain areas in this band are somewhat higher than 20 millicuries of Sr-90 per square mile; for example New York is now about 50.

The strontium-90 reaches the soil with rain, and remains primarily in the upper layer of soil. Approximately 70% is usually found in the upper two inches in soil which has not been disturbed. The concentration varies markedly with depth, and this variation, along with many other factors, affects uptake for given plants. Uptake will be discussed further.

There are two principal factors to consider in the transfer of strontium-90 from dietary food to the human body—to bone: 1) the biological fractionation of strontium and calcium, and 2) the slow metabolic turnover of bone. We have noted that strontium is chemically similar to calcium, and therefore follows calcium through the biological chain. However, the body does prefer calcium, and discriminates against strontium. There is a discrimination factor of two in intestinal absorption, which is to say that the ratio of calcium to strontium in material which traverses the intestinal wall is twice the ratio of calcium to strontium in the diet. There is also a discrimination factor of approximately two between the blood and the bone, due to the preferential excretion of strontium by the kidneys.

Thus the over-all discrimination from diet to bone is about four. Hence a person on an average U. S. diet which contains about 8 micromicrocuries ($\mu\mu$c, or 10^{-12} curies) of strontium-90 per gram of calcium is depositing bone which contains about 2 micromicrocuries of strontium-90 per gram of calcium (the unit micromicrocurie of strontium-90 per gram of calcium has been designated as the Sunshine Unit, or Strontium Unit, S.U.). However, because of the very slow turnover rate of bone the actual values lag considerably behind this figure, especially in adults.

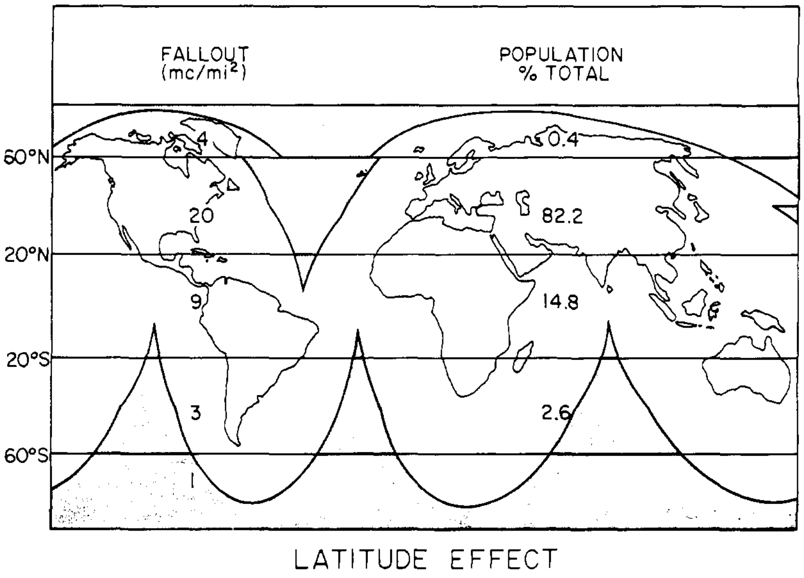
Figure 2 shows the average strontium-90 level in the U. S. diet and the level in the bones of New York cadavers for the past few years; note that whereas both are increasing, the ratio between the two is a factor of 50 or 60 rather than 4.

Figure 3 shows that children are much closer to equilibrium, i.e., they have much higher values. Thus the concentration in young children is about 1 S.U. whereas in adults it is about 0.1 S.U.

It has been predicted that if bomb testing continues indefinitely at the average rate of the past several years, the equilibrium level in the human body will ultimately reach 20 S.U., at which point the intake of strontium-90 would be balanced by losses through excretion and radioactive decay according to its 28-year half life. This level of 20 S.U. is one-fifth the maximum permissible concentration of 100 S.U. for whole populations, based on recommendations of the International Commission on Radiological Protection.

Food Aspects of the Problem

Of the many factors which affect the quantity of strontium-90 which enters plants grown for food, the first to consider is the amount of material on the ground. This is a function of latitude, as noted. It is also a function of rainfall; in a given meteorological area the fallout is generally proportional to the rainfall. Thus in the eastern Mediterranean and the Middle East, where fallout data have been obtained in seven areas varying in rainfall from a low of 2 inches per year in Aden, Saudi Arabia, to 35 inches per year in Beirut, Lebanon, fallout follows rainfall very closely. Also, among thirty stations in southeastern United States which varied in rainfall by a



▲ Source: Various AEC sources

Figure 1. Variation in relative population and Sn^{90} fallout with latitude

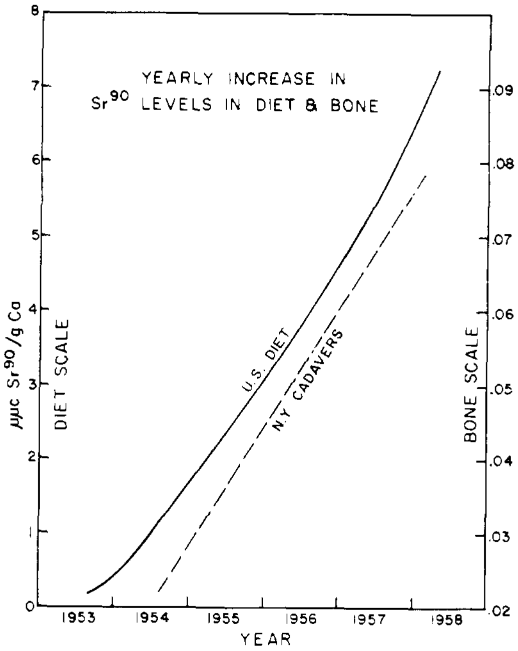


Figure 2. Strontium-90 in diet and bone

Source: The New York cadaver data from Lamont analyses; U.S. diet as derived from Lamont data interpolated with various AEC data ▶

factor of 10 during the spring of 1956, strontium-90 fallout values, with the exception of two or three, follow closely the line of proportionality with rainfall.

A rather dramatic example of this effect is seen in samples of foodstuffs from three locations in Ecuador. Shellmera is at the base of a mountain range and is so situated that waterlogged clouds rise at this point and dump tremendous quantities of rain—exceeding 100 inches per year. Guayaquil, on the other hand, has less than 20 inches of rainfall per year; foodstuffs here have one-tenth or less the concentration of strontium-90 found in the same foodstuffs of Shellmera. Rainfall is not the only factor at work here, however, since the soil of Shellmera—having been leached for ages—is undoubtedly lower in calcium than that of Guayaquil.

This brings up the second important factor which influences the transport of strontium-90 into the plant: the amount of available calcium in the soil. Although this factor is a complex one, it is generally true that increasing the calcium content of the soil—thus decreasing the strontium:calcium ratio—results in a lower strontium-90 entry into the plant. Hence, as our own data and the work of others have shown, liming the soil will usually reduce strontium uptake. Some striking data which we attribute primarily to variations in soil calcium are shown in Table 3. These are values obtained at the same time from five segments of a single milkshed in the northern Great Plains. The extreme values differ by a factor of four.

Some other variables which influence plant uptake are soil tillage, topography, and soil type. Soil tillage factor (called the plowing factor by Libby) takes into account the mixing of debris to the depth of plowing, perhaps 10 to 12 inches. For shallow rooted plants such as grasses, tillage appears to reduce the amount of strontium-90 which gets into the plant. As a result of the topography effect, uptake from hillsides is less than that from level land in the same area, because much of the strontium-90 which falls on hillsides runs off before it can be absorbed by the soil.

Milk and other dairy products represent the major source of calcium in the U. S. diet. The cow very effectively discriminates against strontium, so that the ratio of strontium-90 to calcium in the cow's milk is only one-seventh that in her diet. This does not mean, however, that the ratio in milk which humans consume is only one-seventh the ratio in other foodstuffs they eat, since cows and humans differ in dietary habits. For example, the ratio of strontium to calcium differs throughout a given plant used for food or feed. Thus if the ratio in the stalk of a bean plant is taken as 1, the ratio in the leaf is 0.85 and the ratio in the bean is 0.5. A cow which consumes stalk and all, therefore, gets a higher concentration of strontium-90 in her diet. A second factor is that the ratio in grasses seems generally to be higher than in other vegetable plants. Still another contributing factor is that grazing animals inhale appreciable quantities of surface dust containing strontium-90.

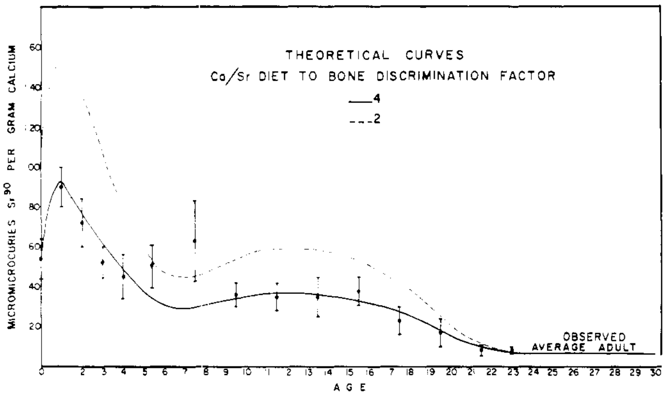
The average concentrations of strontium-90 in U. S. foods today are: cereals, 20 S.U.; vegetables, 12 S.U.; milk, 8 S.U.

There are data to suggest that the strontium-90 in soil is becoming less available with time. In Figure 4 are shown data of the New York Health and Safety Laboratory of the Atomic Energy Commission, both for total fallout and for the average milk levels, in the summer months of each year. In the units given, this ratio varies from 0.27 in 1954 to 0.13 in 1957.

What Is the Hazard?

The hazard represented by current rates of strontium-90 fallout is not completely known, although it probably is very small in comparison with many other hazards to which large populations expose themselves. No effect has been demonstrated at radiation levels anywhere near as low as those involved in fallout.

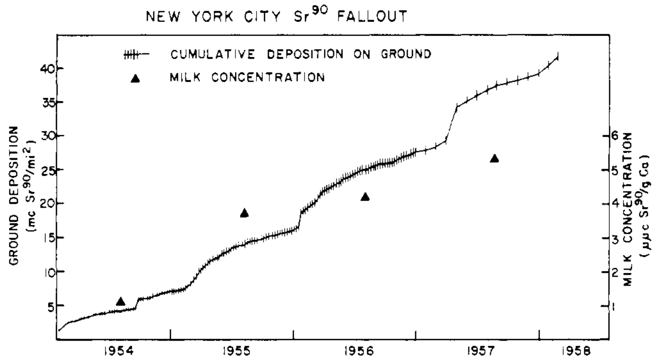
A principal uncertainty involves the question of whether or not there exists a threshold radiation dose below which no damage is done. Geneticists almost universally believe that there is no threshold for genetic damage, although recently some data have been interpreted as casting some doubt on this point. The general consensus is that there is likely a threshold for somatic damage, but it is recognized that the dose-response curve may be defined all the way to zero dose. If one assumes no threshold for somatic injury and on this basis extrapolates the known damage at high levels down to the low levels, one can calculate the effects that might be produced. Thus using the data of Marinelli of Argonne National Laboratory and Hasterlik of the University of Chicago, it is computed that if nuclear testing were to continue at



▲ Source: Lamont data. This figure appeared in *Science*, Feb. 7, 1958, Vol 127, No. 3293, page 272.

Figure 3. Strontium-90 concentration in human bone as a function of age. (Solid line gives result expected from dietary level if discrimination is four. Dotted line gives value if discrimination is two.)

▼ Figure 4. Comparison of strontium-90 fallout and strontium-90 concentration in milk in New York City



Source: Data from U. S. Atomic Energy Commission Report HASL 42

the average rate of recent years, the equilibrium level of strontium-90 in bone would result in three to four thousand cases of bone cancer per year in the total world population. The equilibrium level would not, of course, be reached for many years. Using the data of Lewis of California Institute of Technology, it is calculated that the number of leukemia cases produced would be approximately one-tenth of this value.

It is pertinent to compare the radiation level from fallout with the radiation level to which the human race is subjected from other causes. Thus fallout at the present level gives the human body a radiation of about 5 milliroentgens per year. Potassium-40 gives about 19 per year and cosmic rays give 35 to 60 per year. In the medical area, a chest x-ray gives from 100 to 500 milliroentgens, and a fluoroscopy may give 20,000 milliroentgens. Thus the fallout contribution is comparatively very low, although this of course does not of itself justify the continuance of fallout if it can be avoided.

It is also of interest to consider as a basis for comparison the non-radioactive hazards of modern living. The geneticist Crow of the University of Wisconsin states: "It is quite possible, indeed likely, that among the many new chemicals in our complex industrial society—smoke, food coloring, insecticides, smog, automobile exhaust, preservatives, drugs—some will be found to be a greater somatic or genetic hazard than radiation." Brues of Argonne National Laboratory makes an interesting calculation by which he determines, using the same methods as are used to determine the MPC (maximum permissible concentration) for radiation, that the MPC for cigarette smoking for the population as a whole is about one cigarette every four days. One might also consider the fact that the use of automobiles causes about 40,000 deaths per year in the United States, most of which are unjustifiable. Such facts again do not excuse unnecessary fallout, but they do suggest that this hazard is probably very slight compared to others which we commonly accept.

Obviously, we are not yet near the state where we choose our diet on the basis of its strontium-90 content. It is nonetheless important to investigate means by which strontium-90 intake can be reduced, in the event that such measures are needed in the future. The two avenues of approach are to prevent the isotope from getting into the food, or to remove it by purifying the food after its production.

In the preventive area more research should be conducted on methods of soil treatment to reduce strontium-90 uptake. Consideration might also be given by the food processing industry to shifting food production to regions of lowest fallout in the event of a nuclear war.

Purification is a much more difficult situation. In the case of milk, however, it is possible to remove the strontium-90 by ion exchange; perhaps the nation should be prepared to do this on a large scale should the necessity arise in connection with nuclear war.

Lamont Contribution No. 344, presented before the Division of Industrial and Engineering Chemistry of the American Chemical Society in Chicago, Ill. on Sept. 11, 1958.

Table I. Half-Life Classification of Fission-Produced Radioisotopes

Half-life	Number of Isotopes
Less than 1 day	131
≥1 day <10 days	17
≥10 days <30 days	9
≥30 days <1 yr.	12
≥1 yr. <10 yr.	7
>10 yr. <100 yr.	3
>10^2 yr. <10^4 yr.	0
>10^4 yr.	10
Total	189

Source: General Electric Chart of Nuclides (1956 edition) prepared by G. Friedlander and M. Perlman, and revised by J. R. Stehn and E. F. Clancy

Table II. Sr^{90} Concentration in Vegetables of Ecuador

	$\mu\mu c$ Sr^{90}/Gm. Ca
Shellmera	
Yuca	45.0 ± 1.7
Platano	44.9 ± 4.0
Pano	
Yuca	28.0 ± 0.9
Platano	28.2 ± 1.2
Guayaquil	
Yuca	3.2 ± 0.3
Platano	≤7.2

Source: Lamont analyses

Table III. Variation in Milk Sr^{90} Within Single Milkshed

	$\mu\mu c$ Sr^{90}/Gm. Ca.
1	21.3 ± 0.4
2	35.8 ± 0.8
3	11.2 ± 0.4
4	18.5 ± 0.6
5	8.7 ± 0.4

Source: Lamont analyses