MEASUREMENT OF STRONTIUM-90
IN GEOPHYSICAL AND BIOLOGICAL MATERIALS

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Remarks Prepared by Merril Eisenbud for presentation at a Hearing on "The Nature of Radioactive Fallout and its Effects on Man" conducted by The Joint Committee on Atomic Energy, Washington, D.C. during the week of May 27, 1957.

The properties that make strontium-90 the most hazardous of the nuclides formed in the fission process are its long half-life (28 years) and its chemical similarity to calcium. Because of its resemblance to calcium, Sr-90 may be assimilated by biological processes. If strontium is ingested by human beings in food or water, it will deposit, like calcium, in the skeleton.

Investigation of the potential hazard from contamination of soils and the biological food chains by Sr-90 began very early in the United States atomic energy program. The first studies, associated with the wartime weapons-development program, were theoretical and were designed to identify the principal parameters which influence the long-range effects of nuclear detonations. It was clear, from the start, that studies of radioactive fallout, and of the ultimate fate of Sr-90 in particular, would require the application of knowledge from a wide assortment of the physical and biological sciences. The initial theoretical studies provided a valuable basis for the experimental approach to the problem that became possible with the programs of weapons testing that began in 1948 and have continued intermittently to the present time.

The Sr-90 studies have increased in scope and complexity, and the overall program has, for some years, been global in extent, involving physical, chemical, and biological investigations on land, in the oceans, and in the air. Known as Project Sunshine and directed at a full understanding of the physical and biological behavior of the Sr-90 produced in nuclear detonations, these studies are concerned with an unprecedented variety of scientific questions. From the standpoint of its vast geographic dimensions and the variety of scientific mechanisms involved in the investigation, Project Sunshine rivals the most comprehensive scientific studies ever undertaken.

The factors that influence the behavior of Sr-90 begin in the complex physics and chemistry of the fireball and the mushroom-shaped cloud which forms after a nuclear detonation. The height of the burst above ground, the nature of the terrain, and the particle size of the soil and debris sucked into the fireball, all influence the fallout pattern.

When the particles descend to the earth's surface, they leave the domain of the meteorologist and become involved in the physics, chemistry, and biology of the soil. How soluble is the Sr-90 in fallout? Does it leach from the soil? At what rate is it incorporated into plants, and how can this rate be expressed quantitatively as a function of type of soil and type of plant? These are a few of the questions that have been studied in tracing the Sr-90 into the first of the biological links in the food chain between soil and man. The answers to these and many more questions have been obtained by many investigators working in many laboratories throughout the country.

From its formation in a nuclear detonation until it is metabolized by man, the path of a Sr-90 atom is long and tortuous. Understanding of its route has come from studies which know none of the bounds of any one of the conventional scientific disciplines. The phenomenology of Sr-90 in fallout can be described only in the combined languages of all the principal combined sciences: geophysics, physical chemistry, biophysics, and biological chemistry. Samples are collected throughout the world for Sr-90 analyses. Many of these are sent to the United States for analyses, but others, in increasing numbers, are analyzed in the laboratories of other lands by the many scientists whose data, like our own, are routinely submitted to the United Nations Committee on the Effects of Radiation.

Monitoring for radiostrontium can be divided conveniently into studies of its geophysical and biological distribution. Under the former classification are collected those samples which give us an understanding of the behavior of radiostrontium from its formation in the fireball to its deposition on the surface of the earth and incorporation into soils. The biological studies trace the movements of Sr-90 from the soils and waters through the flora and fauna of the oceans, pastures, and farms, to the skeleton of man. A summary of the AEC sampling program is given in Table I.

Sampling for Geophysical Distribution

Except for immediate fallout in the area of detonation, the original fission products are injected into the troposphere or stratosphere and are geographically distributed by the winds. Radioactive materials are brought down to the surface by precipitation, settling, and, to a lesser extent, by air turbulence.

It is desirable to measure the rate of fallout, its accumulation, and the atmospheric reservoir of material yet to be deposited on earth's surface. The samples currently taken for this program include soils, sea water, collections of fallout in open pots and on gummed film, and collections of atmospheric dust on filters.

Soils

A soil sample can represent the accumulated fallout at any given location. There are many criteria to be met to insure that a soil sample is representative. An ideal sampling site is considered to be an open, level area, undisturbed by cultivation and covered by grass or simple vegetation covering to immobilize the surface. Drainage slopes, silted areas or other unusual drainage conditions should be avoided. Samples are collected with soil augers to give definite areas and depths. The most common division of sampling is to collect the top two inches and the two to six inch layer separately. The known area and the measured weight of sample allow the Sr-90 measurements to be converted to terms of millicuries per square mile.

Removal of Sr-90 from a soil sample is a difficult problem because the relatively low levels of activity currently found require use of very large samples. At present two to four pounds of soil are taken for analysis and this makes the usual procedure of completely dissolving the soil by fusion a practical impossibility. Thus although the fusion technique is the only method certain to remove all Sr-90 from the soil it has been necessary to study other methods for Sr-90 extraction. After considerable experimentation, procedures that agree satisfactorily with the fusion technique have been developed. These involve the extraction of the Sr-90 by electrodialysis or by hydrochloric acid leaching

without completely dissolving the soil. Present evidence leads us to believe that the acid leach removes 85% or more of the Sr-90 and the electrodialysis at least 75%. Some early analyses were obtained by ammonium acetate leaching of the soil, but this method is now felt to be inadequate and none of the data presented here were obtained in this way.

The chemical analysis following extraction requires separation of the Sr-90 from the inactive bulk constituents of the extract and from other radioactive isotopes, which include the natural constituents of the soil and other fission products, including Sr-89.

The major advantage of a soil sample is that it represents the accumulation of Sr-90 at a particular location at the time of sampling. Experimental work has shown that the movement of Sr-90 in the soil is slow enough that adequate samples can be obtained. For example, from 75-80% of the Sr-90 found in the soil is in the top two inches. The disadvantage of soil samples is in the complex and time consuming nature of the analysis.

Sea Water Samples

Since approximately two-thirds of the earth's surface is covered by the oceans, a complete accounting for Sr-90 deposition requires sampling of the oceans. However, in contrast to soils, the Sr-90 in the oceans is distributed through a depth of several hundred feet, at least. The analytical requirements for this type of sample have been beyond the capabilities of the participating laboratories except for samples taken near the Pacific Proving Grounds shortly after a major weapons test. Therefore, studies of distribution in the ocean have been limited to measurements of total fission products and their transport by ocean

currents as a function of time. Such measurements of mixed fission products do not give reliable estimates of Sr-90 in sea water since the fission products may be fractionated by solubility, precipitation, and sedimentation.

Mixed fission products in sea water are concentrated by co-precipitation of the majority of the isotopes with various carriers such as iron hydroxide or calcium carbonate. The activity levels of interest are high enough so that conventional counting equipment can be used for measurement. Extention of the sensitivity by measurement with low background counters would probably not be justified in terms of the overall accuracy of the determination.

Fallout Collections in Open Pots

Stainless steel pots, with a face area of about one square foot, are finding increasing application in fallout sampling. Other types of vessels have been tried and are currently used in some parts of the monitoring program in this country and abroad. The collected precipitation and dust can be analyzed for Sr-90 at intervals, usually on a monthly basis. In sharp contrast to the soil samples, the residues submitted to analysis are essentially free of non-radioactive material. The monthly increment in fallout is readily determined from these samples, while it is only feasible to measure annual increments in soil samples.

The analysis of pot collections requires the separation of Sr-90 from the small amounts of inert material and from other isotopes of mixed fission products. The deposition of naturally occurring radioisotopes during a month is negligible. The levels currently found are such that low background counting equipment is required for satisfactory analysis.

Collection in pots is open to the criticism that more fallout may be collected than would be deposited in the open air. This is caused by impaction on the inner sides of the vessel. Studies are under way to determine the best shape and size of vessel for collections. However, it should be noted that comparison of annual pot increments with soil increments have shown good agreement.

Gummed Film Collections

The need for a simple collecting technique suitable for network operations, where large numbers of collecting stations employ untrained personnel, led to the development of the gummed film collector. This collector has an adhesive surface of one square foot which is exposed for twenty-four hours. A network of up to 200 stations collecting daily samples has been operated by the Health and Safety Laboratory since 1951. Samples are mailed to the laboratory where the analyses are performed. It is not possible to determine Sr-90 directly in gummed film -- first, because the amount of Sr-90 deposited in twenty-four hours is too small, and second, because during rainfall a variable fraction of the Sr-90 is lost by preferential solubility. The Sr-90 component has in the past been estimated by calculation from the mixed product values. In addition, an estimate has been made of the gamma dose resulting from this fallout. The increased weapons test activity has made these calculations extremely difficult and the methods originally followed have been found inadequate. At the present time a new calculation procedure has been devised and is being tested.

The gummed film samples are ashed to reduce their area and the total mixed fission product activity is measured with automatic beta

geiger counters. The activity measurement and the weather data for each sample are entered on IBM cards for calculation and tabulation. The results of this work have been presented in several summary papers.

The gummed film has two major disadvantages. First, it does not allow direct measurement of Sr-90 fallout, and second, from two standpoints it is not a perfect collector of fallout. There are definite indications that there is some wash-off of radioactive material during precipitation. When there is no precipitation the gummed film may collect more activity than would be found on a square foot of a perfect collector since some airborne dust, which would not settle ordinarily, may be scavenged by the gummed surface. Experiments in several locations, however, have shown an average collection efficiency of about 60% and this value is used to correct the measured values obtained in the laboratory. This will be discussed further in a later section.

The advantage of gummed film is its extreme simplicity as a collector and its adaptability to network operation with a central processing facility. In addition, the fact that the gummed film can be measured on a daily basis offers some advantage in detecting the time of arrival of radioactive material. This is particularly useful in the estimation of the low levels of total gamma dose associated with fallout, since the gamma dose at any given location is sensitive to the time of arrival of the fission products.

Atmospheric Sampling

The fission products, including Sr-90, are in particulate form in the atmosphere and the most common air sampling procedure is to draw a large volume of air through a filter. The dust on the filter can then be analyzed for Sr-90 and the atmospheric concentration can be

obtained from a knowledge of the volume of the air sampled. This type of sampling has been carried out at the earth's surface, in the lower atmosphere by jet planes, and in the stratosphere by balloons. The major difference between these samples lies in the amount of air that can be sampled and thus in the activity level which can be collected on a filter.

The analysis consists of the separation of Sr-90 from the inactive constituents of the dust on the filter and the separation from natural radioactive materials and other fission products. Activity levels at the surface or in the lower atmosphere are sufficient that simple beta geiger counters can be used. The volume of air that can be sampled in the stratosphere, when converted by calculation to normal temperature and pressure, is small. Consequently a small amount of particulate material is collected and low background counters are an absolute necessity.

Estimation of the atmospheric reservoir of Sr-90 is needed to predict the level which will be finally deposited on the ground when all the material is deposited. Because of non-uniformity in the distribution of the radioactive debris in the atmosphere, both laterally and vertically, the sampling program must be very extensive to develop a reliable picture.

Air samples at the surface of the earth are the simplest to obtain but are the most heavily influenced by local meteorological conditions. A better estimate can be obtained from stratospheric samples which are the most costly in terms of both sampling and analysis.

At the present time monthly samples at four stratospheric altitudes are being taken at Minneapolis, Houston, Panama Canal Zone, and at one station in the southern hemisphere. This pilot program is designed only to determine the degree of uniformity and thus the extent of sampling required for complete evaluation of the atmosphere.

Biological Distribution

The chemical similarity of strontium and calcium makes it desirable to use the Sr-90:Ca ratio in tracing Sr-90 from soils to man. A useful unit of Sr-90 contamination, first proposed by Libby, is the .micromicrocurie of Sr-90 per gram of calcium (μμc/gmCa). For convenience this unit is frequently referred to as the Sunshine Unit.

The biological distribution of Sr-90 is being studied in its entirety and these investigations have produced a wide variety of data. For this discussion, which is concerned primarily with an evaluation of the potential human hazard from Sr-90, the presentation will be simplified greatly by reviewing only the principal sources of human calcium. The presently observed and predicted future levels of Sr-90 in these foods offer a convenient means of estimating the amounts of Sr-90 that the human skeletons of the future are expected to contain.

In the United States, and many western countries, the main calcium source is milk, with leafy vegetables supplying the majority of the balance. In some areas, such as southeastern United States, this ratio may be reversed. The sources of calcium in countries of the world is under study by the Food and

Agricultural Organization and data on the non-milk drinking populations is slowly becoming available.

The three principal types of samples taken for analysis are (1) vegetation, including both animal and human food, (2) milk, and (3) human bone.

Vegetation

Sr-90 may occur in vegetation in either of two routes. Sr-90 from the soil may be taken up by the root system and incorporated into the plant. In addition, fallout may be directly deposited on the plant. Part of this latter material may be washed off by rain but a considerable portion apparently is retained. The relative distribution of Sr-90 in the plant and on the outer surfaces may be quite variable, depending on the amount of fallout and the type of soil.

The type of vegetation selected depends on whether it represents food for animals or for humans. For human foods the samples can be taken from the consumer market. The analysis of vegetation is simpler than for soils or for fallout collections since the amount of inactive material is small related to the amount of Sr-90, and because the plant discriminates against many of the radioactive isotopes. Analysis still requires, however, separation of Sr-90 from the inactive constituents of the plant ash and from other radioisotopes which are present.

Milk

The major source of body calcium in the United States is milk, hence its analysis has received considerably more attention than

that of any other food stuff although other foods may have a higher Sr-90 to Ca ratio. As a matter of fact, cow's milk contains less strontium per gram of calcium than do the vegetables which comprise the balance of our calcium intake. This is because, as noted by other speakers, biological processes in general tend to discriminate against strontium. Milk contains less strontium per gram of calcium because the calcium has passed through two biological processes. The strontium has passed through the vegetable and then through the cow. Thus the Sr-90 has been selectively eliminated by two stages in the case of milk and only one stage in the case of a vegetable. Nevertheless, milk seems to be the best possible index to human exposure to Sr-90 because it is the source of 80-90% of the calcium in the skeletons of American adults. Moreover, it is a material which is relatively easy to sample and the samples represent the pooling of milk from large geographical areas.

Monthly analyses of milk samples are available from six major milk sheds in the United States, for periods ranging from one to four years. The sampling procedures have been designed to follow the exposure level of the human population at the location rather than to follow an individual farm or even an individual processing plant.

The determination of Sr-90 in milk is a relatively simple procedure, since the cow discriminates sharply against other fission products. The main analytical problem is the separation of Sr-90 from the large amount of calcium present.

The chief advantage of following milk as a monitoring device is that it yields an immediate estimate of the amount of Sr-90 which man will ingest. This is more direct and more reliable than attempting to predict the movement of Sr-90 to man from analyses of fallout or of soil.

Human Bone

Analyses of human bone afford a direct measure of the Sr-90 level at a given time. However, as previously mentioned, human bone is not yet in equilibrium with the Sr-90 of the environment. Thus, measurements made at the present time are only of value when viewed in relation to other materials, particularly human food and the present and predicted levels of Sr-90 on the earth's surface.

Human bone samples show the lowest levels of Sr-90 of any biological material being analyzed. This means that a large sample of bone is required for analysis and such specimens are not always readily obtainable. The extensive program at the Lamont Geological Observatory has yielded several hundred autopsy specimens from all over the world. Dr. Kulp, who is in charge of this work at Lamont, will report on this work in detail.

The analysis of bone requires the separation of Sr-90 from large quantities of calcium but only negligible amounts of other radioisotopes are present. The current levels require not only low background counting equipment but the most extreme care in the prevention of contamination of samples with other radioactive materials.

Discussion of Findings

We have seen that many kinds of samples are being collected routinely from a large number of locations, and that the Sr-90 in these samples serves as a tracer for the study of many physical, chemical and biological processes. In this discussion, an effort will be made to simplify the analyses of the data and to deal only with those portions of the overall Sunshine program that are concerned with an estimate of the human hazard from Sr-90.

The fundamental questions which must be answered are these:

1. How much Sr-90 has been deposited on the earth's surface?

2. How much Sr-90 from detonations to date remains suspended in the upper atmosphere and how long will it take tp precipitate?

3. How much Sr-90 will human skeletons contain when they are in equilibrium with the expected levels of Sr-90 in soil?

Deposition of Sr-90 in Earth

As noted earlier there are two basic procedures by which the wide spread deposition of Sr-90 can be documented. The first, and the most direct, is by the collection of soil samples and their analysis for Sr-90.

The soil analyses for the year 1956 are plotted in Figures 1 and 2, which gives the estimates of Sr-90 deposition in millicuries per square mile. Similar data has been obtained on the basis of samples collected from the gummed film network. These data are summarized in Figures 3 and 4 which give the estimated cumulative Sr-90 distributions as of July 1, 1956. In recent

months a third method has been adopted, utilizing pots which have been located at 21 stations throughout the world but too few data are available to justify presentation at this time.

It will be noted that the estimates of fallout obtained by analyzing soil samples are lower than those obtained by gummed film collection. The differences can be seen in Table 4 which summarizes the observation of both the soil sampling and the gummed film network by zones. The estimated world-wide fallout of Sr-90, based on the gummed film samples is 1.5 megacuries compared to .88 megacuries as estimated by soil samples. It is also noted that the soil data indicate a greater degree of latitudinal variation than the gummed film data. In the latter case the mean deposition in the North Temperate Zone is relatively high with respect to the somewhat uniform deposition elsewhere in the world. The data derived from soil samples likewise indicate a higher deposition in the North Temperate Zone but there is less uniformity elsewhere in the world and a North-South gradient is quite evident.

The reason why the soil samples yield lower values is not clear. The integrated fallout as estimated by soil analyses is only 55% of the value obtained from the gummed film observation. As noted earlier it is possible that the Sr-90 is incompletely removed from the soil by chemical analysis and this may account for some, but certainly not all, of the difference. The gummed film tends to yield results which are comparable to the Sr-90 measurements of pot samples but it is possible that both the

pot and the gummed film tend to concentrate fallout, particularly on dry, windy days. It is also possible that some of the Sr-90 has been leached beyond the sampling depth. At the present time, there is insufficient knowledge to explain the difference between the two methods. One megacurie, being intermediate between the two estimates, is perhaps the most reasonable approximation of the total amount of Sr-90 deposition on the earth by delayed fallout in mid-1956.

The test firings in Nevada only partly account for the relatively elevated deposition in the North Temperate Zone. There is evidence that much of the differentiation between the North Temperate Zone and the rest of the world can be attributed to the preferential fallout in this region from 1954 series in the Pacific (Operation CASTLE). By mid-1956 fallout from the USSR tests did not account for a major fraction of the total observed fallout.

Stratospheric Reservoir

An estimate of the future distribution of Sr-90 may be obtained from the above data plus knowledge of the amount of Sr-90 suspended in the upper atmosphere, and the rate at which it precipitates to earth's surface. The direct method of measuring the straos-pheric reservoir is to obtain samples, using balloons or high flying aircraft. This has been done intermittently since 1953 but the data are too few to permit one to estimate by this method, with any degree of confidence, the total inventory of stratos-pheric Sr-90.

Using a more indirect procedure, Libby suggested a value of 2.4 megacuries of Sr-90 in the fall of 1956. This estimate is based not on direct measurements in the stratosphere, but rather on what might be described as material balance studies. The amount of Sr-90 produced in detonations, to date, can be estimated with some certainty. Estimates of the amounts of Sr-90 that are deposited in the intense fallout in the vicinity of a detonation are available from extensive investigations conducted during the test programs in Nevada and in the Pacific. The total strontium produced in a detonation, less the Sr-90 which falls out in the immediate vicinity of the detonation, gives the total inventory of Sr-90 that is available for subsequent deposition at places remote from the site of detonation.

It is apparent that the rate of precipitation of the Sr-90 must be considered in any estimation of future hazard. If the time of descent was infinitely great, the Sr-90 would decay before it reached the earth's surface and it would not constitute a potential hazard. Actually, we have learned that the time of descent is relatively short in relation to the half-life of Sr-90. Libby has estimated that the average residence time is approximately 10 years. In mathematical terms this would be equivalent to a half-life of 7 years. It is possible this estimate is too long and the average life is as little as 6-7 years (half-life about $4\frac{1}{2}$ years).

Our discussion of the foreseeable levels of Sr-90 will thus be simplified by the assumption that the material now contained in

the stratospheric reservoir will be completely deposited on the earth's surface before any radioactive decay has occurred. Moreover, it will be assumed that the geographical distribution in the future will follow approximately the same distribution as has been true of the deposition of stratospheric debris in the past. This will tend to introduce an error on the side of safety since it would be expected that future fallout would be more uniform than in the past.

Future Estimate of Sr-90 in Man

As noted earlier, it will be assumed that essentially all of the 2.4 megacuries of Sr-90 stored in the stratosphere in mid-1956 will be deposited on earth's surface. This will have occurred by about 1970. It will be further assumed that stratospheric fallout in the future will be distributed in approximately the same pattern as the past.

This discussion of future levels of Sr-90 in man will be based on data for the North Midwestern and Northeastern United States, where fallout is as high as in any region of the world for which data are available. The fallout levels in mid-1956 ranged from 19 to 33 millicuries per square mile, the average being 25 mc/mi^2. Of this, about 6 mc/mi^2 is the result of tropospheric fallout from tests prior to mid-1956. The stratospheric fallout of the past may thus be estimated as 19 millicuries per square mile. This was the level which existed when the world-wide deposition of Sr-90 was about 1 megacurie. When the 2.4 megacuries now in the stratosphere has deposited, the deposition in Northern United States may

thus be estimated to be 45 millicuries per square mile, about 1.8 times the level in mid-1956.

To define the potential risk from a given distribution of Sr-90 on the surface of the earth requires that the distribution be quantitatively related to the skeletal burden of Sr-90 of a human population in dietary equilibrium with the soil from which its nourishment is derived. This equilibrium is already established for a variety of trace elements normally present in the earth's crust. Some of these, like potassium and radium, are radioactive, and this is reflected by the presence of these substances in the human body. For example, the upper foot of soil in the United States contains, on the average, about 1000 millicuries of radium per square mile. The average adult skeleton in this country contains about 10^{-4} microcuries of radium, which is derived from assimilation of this trace element from foods and water. Thus, the value of 10^{-4} microcuries of radium represents the amount deposited in the skeletons of the populations whose mineral metabolism is in equilibrium with the soil minerals.

The freshly deposited Sr-90 takes a relatively long time to complete the biological route to bone. At the present time the

skeletons of all but very young children were formed prior to the introduction of Sr-90 to the soil. Moreover, bone being formed at the present time utilizes calcium which left the soil in months gone by. The fact that cattle may be fed on hay many months old and the hold-up of human foods in the commercial distribution system are but two of many factors which would lead one to expect the human Sr-90 burden to lag in time behind the potential value which might ultimately be expected from a given soil concentration. The human skeleton cannot be expected to respond quickly to the gradual accretion of Sr-90 by soil. Equilibrium can be expected to be achieved over a period of years but not over a period of months.

In the United States, as in a number of other parts of the world where the population derives much of its calcium from dairy products, analyses of milk for Sr-90 provide a convenient method of estimating the levels of human absorption which may be expected in the future.

During periods of actual fallout the concentration of Sr-90 in milk originates from two sources: the Sr-90 level may have been metabolized from the soil by normal root uptake or it may have short circuited the soil by having been deposited directly on the leaf with which it is ingested by the cow. The presence of the latter fraction is dependent on current fallout. If all detonations ceased, the fraction due to direct deposition on the leaf surfaces would diminish with the reduction in the rate of fallout. With the cessation of fallout this fraction would be

eliminated altogether. In contracts, the Sr-90 of the soil constitutes a relatively long lived reservoir for future uptake. Diminution will result only from radioactive decay or if the Sr-90 is leached beyond the root zone.

At the present time, it is not known to what extent the Sr-90 which occurs in milk may be due to direct deposition on leaves. This fraction presumably diminishes with time as the accumulation in soil increase and the rate of fallout remains approximately constant. For our purposes it will be assumed that all of the Sr-90 in milk is metabolized by way of the roots. This is a conservative assumption which tends to exaggerate the forecast of future levels.

The milk in a large metropolitan area for which data are available since early 1954, averaged 5 μμc/g Ca in October 1956 when the soils were sampled. If we neglect the effect of fresh fallout, and further assume that the Sr-90 in milk is proportional to the amount in soil, the future level may be estimated as 5.0 x 1.8 = 9 μμc Sr-90/g Ca. This prediction is in good agreement of 8.3 μμc/g Ca which was similarly estimated by the data available in the summer of 1955.

In a previous publication it was assumed that applying a factor of 3 to these particular milk values would be ample to define the upper limit of hazard elsewhere in the United States. This factor of 3 continues to appear reasonable. On this basis the maximum foreseeable concentration in milk would approximate

27 μμc Sr-90/g Ca compared to 25 μμc Sr-90/g Ca based on data available in the summer of 1955.

A number of individuals have raised the question as to whether a discussion of average fallout values is adequate to define the upper limit of hazard to people exposed to unusually heavy fallout. In this connection it is worth noting that as the data continue to accumulate from every corner of the globe the deviations from average that are noted are the deviations in the safe direction. Whereas fallout values are rarely reported more than twice the mean for any given region, it is not uncommon to observe values which are of the order of 10% of the average.

Our final problem is to estimate the burden of Sr-90 which will be attained by a population whose principal dietary source of Ca contains 25 μμc/g Ca. As has been noted by previous speakers, it is known that human metabolism involves some measure of discrimination against strontium and in favor of calcium. Based on the data now available a child being nourished on milk containing 25 μμc Sr-90/g Ca would be expected to develop a skeleton containing Sr-90 in somewhat lower concentrations than this value but probably higher than 10 μμc Sr-90/g Ca. Thus 10-20 μμc/g Ca may be said to be the highest foreseeable value that will be attained by the populations of the future from nuclear devices detonated up to late 1956. A value of 15 μμc/g Ca will be taken as a basis for discussion.

It should be noted that this estimate includes a number of assumptions which are deliberately conservative. No allowance has been made for the radioactive decay which will take place before the Sr-90 descends from the stratosphere to the earth. This may diminish the amount of available Sr-90 by about 25%. The assumption that all the Sr-90 in milk originated by root uptake is another conservative assumption. It has been estimated that 30% of the Sr-90 in milk in 1956 originated by direct foliar deposition. Another conservative assumption is that the Sr-90 remains in the root zone of the vegetation. It is likely that over a period of many years an appreciable fraction will leach below the root zone.

The combined effect of these and other safety factors is appreciable. It is probable that the maximum human burden from detonations which occurred up to late 1956 will be somewhat lower than 15 μμc/g Ca. It is likely that 15 μμc/g Ca overestimates the true value by a factor of at least 2 and possibly as much as 5.

Assuming 15 μμc Sr-90/gm Ca to be the maximum value to be attained, one can calculate that this amount of Sr-90 will deliver a dose of 1.4 rads to the skeleton over a life time of 70 years. This compares with a normal skeletal irradiation of 7 to 30 rads resulting from potassium 40, carbon 14, cosmic rays, terrestrial gamma radiation and radium. The maximum foreseeable value of 15 μμc Sr-90/g Ca is thus equivalent to 4.5 to 18% of the dose from natural sources of skeletal irradiation.

TABLE 1

SCOPE OF Sr^{90} SAMPLING PROGRAM

Type Sample	Frequency	Number of Stations	Total Number Per Year
Soil (U.S.)	Annually	17	17
Soil (Foreign)	-	-	-
Gummed Film (U.S.)	Daily	39	14,235
Gummed Film (Foreign)	Daily	66	24,090
Pots (U.S.)	Monthly	7	84
Pots (Foreign)	Monthly	14	168
Milk (U.S.)	Monthly	5	60
Milk (Foreign)	Monthly	2	24
Tap Water (New York)	Monthly	1	12
Canned Fish	Monthly	5	60
Pasture Program (U.S.)	Annually		
Soil		7	168
Vegetation		7	168
Animal Bone		7	168
Sea Water (Pacific)	Monthly	50	600
Stratosphere	Monthly	5	240
Human Bone	-	20	about 1200

TABLE 2

CUMULATIVE FALLOUT DATA FROM GUMMED FILM THROUGH JUNE 1956

WORLD

	Station	Sr^{90} mc/mi^2
1	Anchorage, Alaska	8.7
2	Edmonton, Alberta	12.2
3	Regina, Saskatchewan	9.5
4	Winnepeg, Manitoba	11.4
5	Churchill, Manitoba	3.9
6	Moosoonee, Ontario	9.0
7	North Bay, Ontario	10.8
8	Ottawa, Ontario	8.7
9	Montreal, Quebec	11.0
10	Seven Islands, Quebec	7.8
11	Moncton, New Brunswick	9.8
12	Goose Bay, Labrador	8.6
13	Stephenville, Newfoundland	13.5
14	Thule, Greenland	5.8
15	Keflavik, Iceland	9.3
16	San Juan, Puerto Rico	12.1
17	Bermuda	13.9
18	Mexico City, Mexico	11.6
19	San Jose, Costa Rica	4.8
20	Panama Canal Zone	6.4
21	Bogota, Colombia	6.3
22	Quito, Ecuador	3.6
23	Lima, Peru	3.6
24	La Paz, Bolivia	6.2
25	Belem, Brazil	5.8
26	Sao Paulo, Brazil	5.0
27	Buenos Aires, Brazil	5.6
28	Prestwick, Scotland	11.2
29	Oslo, Norway	7.9
30	Rhein Main, Germany	9.4
31	Sidi Slimane, Morocco	14.5
32	Tripoli, Libya	15.9
33	Dakar, French West Africa	6.2
34	Lagos, Nigeria	4.1
35	Leopoldville, Belgian Congo	5.5
36	Addis Ababa, Ethiopia	7.1
37	Pretoria, Union of South Africa	4.2
38	Durban, Union of South Africa	2.4
39	Colombia, Ceylon	6.5
40	Singapore, Malaya	6.1

TABLE 2 (Contd.)

	Station	Sr^{90} mc/mi^2
41	Misawa, Japan	13.9
42	Tokyo, Japan	12.7
43	Hiroshima, Japan	13.1
44	Nagasaki, Japan	14.8
45	Kadena, Okinawa	-
46	Taipei, Taiwan	18.3
47	Manila, Philippine Islands	11.1
48	Iwo Jima	30.5
49	Yap, Caroline Islands	14.6
50	Guam, Caroline Islands	15.8
51	Truk, Caroline Islands	14.0
52	Ponape, Caroline Islands	18.2
53	Wake Island	10.1
54	Noumea, New Caledonia	6.8
55	Sydney, Australia	5.2
56	Melbourne, Australia	6.0
57	Wellington, New Zealand	3.6
58	Honolulu, Hawaii	13.0
59	Johnston Island	16.1
60	Canton Island	6.0
61	Dhahran, Saudi Arabia	7.3
62	Beirut, Lebanon	18.5
63	Bangkok, Thailand	8.3
64	Nairobi, Kenya	4.2
65	Monrovia, Liberia	7.1
66	Lagens, Azores	15.6
67	Nome, Alaska	5.7
68	Fairbanks, Alaska	11.8
69	Juneau, Alaska	8.4
70	French Frigate Shoals	13.6
71	Midway	12.1
72	Koror	11.1
73	Lihue	10.0
74	Hilo	19.7

TABLE 3

CUMULATIVE FALLOUT DATA FROM GUMMED FILM THROUGH JUNE 1956

UNITED STATES

	Station	Sr^{90} mc/mi^2
101	Detroit, Michigan	16.0
102	Louisville, Kentucky	14.1
103	Knoxville, Tennessee	10.5
105	Memphis, Tennessee	15.7
108	Atlanta, Georgia	11.0
115	Philadelphia, Pennsylvania	12.7
116	Pittsburgh, Pennsylvania	18.0
117	New York (La Guardia)	16.7
118	Binghamton, New York	8.9
122	Rochester, New York	12.9
127	New Haven, Connecticut	12.0
132	Jacksonville, Florida	7.9
133	Miami, Florida	12.1
134	Washington, D. C.	12.0
137	Cleveland, Ohio	15.9
138	Cape Hatteras, North Carolina	9.4
139	Concord, New Hampshire	8.0
141	Boston, Massachusetts	13.8
204	Corpus Christi, Texas	6.3
206	Dallas, Texas	12.9
209	Wichita, Kansas	14.7
211	Scottsbluff, Nebraska	12.7
212	Rapid City, South Dakota	11.6
216	Minneapolis, Minnesota	16.4
219	Des Moines, Iowa	15.5
221	St. Louis, Missouri	18.9
222	Chicago, Illinois	14.5
225	New Orleans, Louisiana	13.6
304	Boise, Idaho	18.5
309	Billings, Montana	14.9
310	Salt Lake City, Utah	34.6
314	Tucson, Arizona	15.2
321	Grand Junction, Colorado	27.7
323	Albuquerque, New Mexico	34.9
326	Las Vegas, Nevada	17.8
401	Seattle, Washington	13.4
404	Medford, Oregon	8.9
407	San Francisco, California	8.9
410	Los Angeles, California	6.8
	Mean	14.2

TABLE 4

REGIONAL Sr^{90} FALLOUT
CUMULATIVE TO JUNE 1956

Region	SOIL			GUMMED FILM		
	Number of Locations	Average mc/mi^2	Total Megacuries	Number of Locations	Average mc/mi^2	Total Megacuries
Artic	3	2.2	.02	1	5.8	.04
N. Temperate	33	9.4	.49	70	12.8	.67
N. Tropic	9	3.9	.15	20	9.1	.35
S. Tropic	7	2.0	.08	8	5.2	.20
S. Temperate	16	2.6	.14	6	4.6	.24
Total			.88			1.50
United States	17	20.5	.06	39	14.2	.04

TABLE 5

DRIED MILK ANALYSES

Sr^{90}

Micromicrocuries Per Gram Calcium

	1	2	3	4	5	6	7	8
April, 1954	0.47							
May	1.2							
June	1.3							
July	1.5							
August	1.2							
September	1.5							
October	1.4							
November	1.1							
December	0.64							
January, 1955	2.5						3.0	
February	0.77						1.0	
March	0.75						2.0	1.8
April	0.31						1.8	2.9
May	1.9	2.6	4.1	1.0	7.3	1.7	1.9	
June	2.5	4.7	4.6	4.6	9.2	2.6	0.8	5.5
July	1.9	4.4	3.9	0.8	6.3			2.6
August	2.0	4.1		1.2	5.8		0.8	
September	1.5	3.2		3.3	4.7		2.0	
October	2.8			4.4	6.9		7.5	
November	2.5			3.7	7.4		2.5	
December	3.3			3.0	10.		3.5	
January, 1956	2.3			3.0	3.5		2.7	4.0
February	2.0			3.5	8.1			
March	2.0	6.3		3.4	11.		3.5	
April	2.9	6.7		3.4	9.6	5.2	3.0	4.6
May	2.8	4.9		2.8	17.	6.4		4.5
June	3.0	4.4		3.4	8.7	5.0		5.0
July	2.7	6.1		4.2	6.6		2.3	
August	3.1	3.8		4.7	8.6			
September	4.9	4.8		4.3	10.7		2.7	
October	5.4			4.72	8.9			
November	5.6				3.6			
December								

Locations

1 Perry, New York
2 State College, Mississippi
3 St. Louis, Missouri
4 Columbus, Wisconsin
5 Mandan, North Dakota
6 Portland, Oregon
7 Japan
8 United Kingdom

MONTHLY ANALYSES OF DRY MILK EASTERN UNITED STATES