To Al Klement

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Cæsium-137 in Dried Milk Products in Relation to Phytoclimatic Zones

A RECENT evaluation of radiological data gathered by the U.S. Atomic Energy Commission's Health and Safety Laboratory includes a statement that the concentration of fission products in commercial milk is essentially independent of total rainfall[1,2]. However, the precipitation values were presented as arbitrary ranges and the landscape units used were not strictly biological regions. The purpose of this communication is to show that if radiological data from the same source are arranged according to natural landscape units a relationship between phytoclimatic zones and the cæsium-137 content of milk is indicated.

For our purpose, the geographical region considered is the north-western portion of the United States where broad areas are mapped as distinctive natural vegetation zones[3]. Such broad areas are necessary to allow reasonable assurances that milk sample stations actually derive milk from an area representative of a particular vegetation zone.

Ten of eleven milk sampling stations in the north-west region were grouped into one of three natural vegetation zones (Table 1). Portland, Oregon and Burlington, Washington, were assigned to the Pacific north-west coniferous forest zone. Bismarck, Bottineau, and Cando, North Dakota; and Mitchell, South Dakota, were assigned to the grassland zone. Sunnyside, Washington; Payette and Idaho Falls, Idaho; and Monroe, Utah, were assigned to the sage-brush zone. Because of its proximity to the Wasatch Mountains, which provided a diversity of vegetation zones within a small area, the milk sampling station of Ogden, Utah, was excluded.

Cæsium-137 is deposited on aerially exposed plant parts directly from the atmosphere and the amounts ingested and assimilated by grazing animals are dominantly from this source rather than from plant uptake via contaminated soils[4]. Total precipitation is regarded as important in depositing cæsium-137 over landscapes and the amounts deposited are related to the amount of precipitation; moist regions receive more cæsium-137 than regions of less moisture[5].

The cæsium-137 content of milk samples in pc./g potassium from stations grouped according to vegetation zones is presented in Table 1. Milk products from sampling stations in the coniferous zone averaged 90 pc./g potassium as compared with only 54 and 37 for grassland and sage-brush zones. Total precipitation from weather stations

Table 1. AVERAGE CÆSIUM-137 PC./G POTASSIUM IN DRIED MILK PRODUCTS AND PRECIPITATION FOR MILK SAMPLING STATIONS IN THE NORTHWESTERN UNITED STATES, JANUARY 1959–JUNE 1960, GROUPED ACCORDING TO NATURAL VEGETATION ZONES

Vegetation zone	Sample station	No. of samples	avg. ^{137}Cs pc./g K	Precipitation total inches	% of ppt in winter months
Coniferous forest	Portland, Oreg.	65	89	67	52
	Burlington, Wash.	75	92	55	47
			avg. 90	avg. 61	
Grassland	Bismarck, N.D.	67	65	20	10
	Bottineau, N.D.	77	51	29	5
	Mitchell, S.D.	58	42	37	12
	Cando, N.D.	31	48	—	—
			avg. 54	avg. 29	
Sage-brush	Sunnyside, Wash.	78	22	9	55
	Payette, Ida.	70	43	18	49
	Idaho Falls, Ida.	73	49	9	28
	Monroe, Utah	73	34	—	—
			avg. 37	avg. 12	

near the milk sampling stations showed the coniferous forest zone stations as receiving an average of 61 in. from January 1, 1959, until June 1960. This was compared with an average of only 29 and 12 in. from grassland and sage-brush zones respectively. It is realized that precipitation readings from a few stations probably do not represent an accurate measurement of the precipitation over the entire milk harvest areas; nevertheless, natural vegetation reflects the biological effectiveness of precipitation and the boundaries of these may be used to delimit long-term biological climates. It has long been recognized by plant ecologists that total annual precipitation in the north-western United States is not sufficient to differentiate sage-brush and grassland zone climates[6]. The seasonal distribution of precipitation in the sage-brush zone is concentrated in winter months, while that of the grassland zone is concentrated in spring and summer (Table 1). Seasonal precipitation could greatly influence the amounts of cæsium-137 deposited on foliar surfaces. In temperate climates having a definite seasonal agricultural yield foliar deposited cæsium-137 reflects the amounts largely accumulated during the summer photosynthetic period. Forages grown in the semi-arid sage-brush zone seldom experience summer precipitation and growth water is supplied by irrigation. In the grassland zone growth of forage crops and summer precipitation coincide to yield higher cæsium-137 values in contrast to the non-synchrony of biological and meteorological events and lower cæsium-137 values in the sage-brush zone.

The higher average cæsium-137 content of dried milk products produced in the moist forest zone appears related to the greater precipitation in this zone in contrast to the grassland and sage-brush zones. The lower average cæsium values in milk products produced in the sage-brush zone in contrast to grassland zone appear as a result of a non-synchrony of phenological and meteorological events induced by land management practices.

To test statistically the effect of vegetation zones in

/G POTASSIUM IN DRIED MILK PRODUCTS SAMPLING STATIONS IN THE NORTH- Y 1959–JUNE 1960, GROUPED ACCORDING VEGETATION ZONES

o. of mples	avg. ^{137}Cs pc./g K	Precipitation total inches	% of ppt in winter months
65	89	67	52
75	92	55	47
	avg. 90	avg. 61	
67	65	20	10
77	51	29	5
58	42	37	12
31	48	—	—
	avg. 54	avg. 29	
78	22	9	55
70	43	18	49
73	49	9	28
73	34	—	—
	avg. 37	avg. 12	

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m-137 content of dried milk moist forest zone appears itation in this zone in contrast rush zones. The lower average ducts produced in the sage- ssland zone appear as a result nological and meteorological agement practices.

effect of vegetation zones in relation to the cæsium-137 content of milk an analysis of variance was performed which included seasonal effects. The hypothesis of no zonal effect was rejected at the 1 per cent level of significance. Additional inferences were obtained by subsequent tests for judging contrasts[7]. All three contrasts between means were significant at the 1 per cent level. The computed values: $\psi_1 \gg 12$ pc. cæsium-137/g potassium; $\psi_2 \gg 32$ cæsium-137 pc./g potassium; where ψ_1 is the difference between the means of the grassland zone and the sage-brush zone and ψ_2 is the difference between the means of the forest and grassland zones.

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W. H. RICKARD
A. D. WIGGINS
J. K. FREMSTAD

Biology Laboratory,
Applied Mathematics Operation,
Hanford Laboratories,
General Electric Co.,
Richland, Washington.

[1] Kulp, J. L., Schulert, A. R., Hodges, E. J., Anderson, E. C., and Langham, W. H., *Science*, **133**, 1768 (1961).
[2] *Health and Safety Lab. Strontium Program, Quart. Summary Rep., HASL-77* **88**, 95 (1960).
[3] Shantz, H. L., and Zon, R., in *Atlas of American Agriculture*, Pt. 1, Sect. *E*, 29 (U.S. Dept. Agric., Washington, D.C., 1924).
[4] Langham, W. H., and Anderson, E. C., *Health Phys.*, **2**, 30 (1959).
[5] Löw, K., and Edvarson, K., *Nature*, **187**, 736 (1960).
[6] Daubenmire, R., *Plants and Environment* (Wiley and Sons, Inc., New York, 1947).
[7] Scheffé, H., *The Analysis of Variance* (Wiley and Sons, Inc., New York 1959).

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SIGNIFICANCE OF STRONTIUM-90 IN MILK. A REVIEW

B. L. LARSON AND K. E. EBNER
Laboratory of Biochemistry, Department of Dairy Science,
University of Illinois, Urbana

SUMMARY

Milk has received attention as a source of strontium-90 (Sr-90), since it is the major source of calcium and, hence, Sr-90, in the diet of most Western countries. Although several biologically active radioactive isotopes are produced in a uranium-235 atomic bomb explosion, Sr-90 is the major problem when considering long-term fallout, because of its slow fallout from the atmosphere, its long half-life of 28 yr., and its biological similarity to calcium. There are several discrimination steps against Sr-90 in its route to the bones of man after its deposition in soil from the atmosphere. These include the plant, the gut, the kidneys, the placenta, and the mammary gland. Compared to bone radiation received from other natural sources, the radiation from Sr-90 present in bone constitutes a small proportion, both now and if nuclear tests continue at the same rate. Milk contains much less Sr-90 per unit of calcium than do vegetables and cereals because of several discrimination factors in its formation, including the mammary gland. A comparison of diets consumed by various countries of the world indicates that those countries consuming a higher percentage of milk have lower relative Sr-90 intakes in their diets. Reliable data from which to draw sound conclusions are crucially lacking in many areas of the long-term fallout problem. The present knowledge strongly suggests that the current and projected levels of Sr-90 in milk should not cause us concern when compared to radiation received from natural sources; but further studies are necessary to be certain if this is true.

Although man has been concerned with the damaging effects of radiation for the past 30 yr., the threat of nuclear warfare and the current controversy over the testing of atomic devices have brought the problem to the immediate focus of public attention. The public has been made aware of the accumulation of radioactive materials from nuclear debris in its environment and of the possible damaging effects of this increase in radiation. In particular, the passage of strontium-90 (Sr-90) from the atmosphere into food and its accumulation in bone have been publicized.

It is recognized that milk is the principal source of calcium (and, hence, Sr-90) in the diet of most Western countries, including the United States. Various opinions on the significance of this fact have been advanced. One investigator *(3)* has proposed that all the calcium (and Sr-90) present in milk should be removed and replaced with calcium from uncontaminated "ancient sources"; conversely, it has been concluded that the levels of Sr-90 in milk are so low that we need not be concerned *(24)*.

The recognition of how much Sr-90 is present in milk and an interpretation and comparison of this level with that present in other food products, is of practical importance to the dairy industry. It is the opinion of the authors that there has been too much willingness on the part of the dairy industry to allow others not concerned with the industry to collect and to interpret the basic information relative to milk. Accusing fingers have been pointed at milk without proper

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regard to the implications involved, with the result that the position of milk as an essential foodstuff, in the opinion of the American public, has been questioned.

The purpose of this review is to evaluate the available data on the accumulation of Sr-90 in milk and other foods and to discuss its significance. This review will be limited chiefly to the question of long-term radioactive fallout, since Sr-90 is not an important nuclide in the fallout resulting shortly after a nuclear explosion.

Background information. It is important for an understanding of the radioactive fallout problem to consider the primary nuclear reactions causing fallout, and to trace briefly the concern of scientists over the problem as it developed *(19i)*. In its early inception, the major problem was to win the war and little consideration was given to long-range fallout effects on behalf of the general population. In 1949, Dr. N. M. Smith of Oak Ridge undertook a theoretical analysis on the long-range aspects of fallout and, as a result, in 1952 Rand Corporation was given a special contract to make an independent study on the potential dangers of radioactive fallout. In the summer of 1953, at a conference called to review the Rand report, it was recommended that a study of mixed fission products be made, with emphasis being placed on Sr-90. As a result of this meeting, Project Sunshine was born, with Dr. W. F. Libby as its director. The immediate aim of this project was to analyze samples of soil, plants, animals, dairy products, human bone, and other materials from the United States and other parts of the world for levels of Sr-90. Originally, Project Sunshine was concerned with Sr-90 analyses, but now it is concerned generally with all phases of the fallout problem.

In late May and early June of 1957, the special Subcommittee on Radiation of the Joint Committee on Atomic Energy of the Congress of the United States, held investigations on the nature of radioactive fallout and its effects on man. Testimony and statements given at these hearings concerned all phases of the fallout problem and subsequently were published in a comprehensive 2,065-page report *(19)*. The release of this report made available the first major unclassified source of information relative to Sr-90 levels in milk, other foods, and forages. Unfortunately, some of the evidence and conclusions presented were undocumented with data; however, much has appeared in print since that time.

The units used to discuss radioactive phenomena are numerous and are apt to become confusing, since the terminology is not rigorous. The common terms used, as well as the specific term used to denote the concentration of Sr-90 in milk and other materials, are summarized in the Appendix.

Formation of Strontium-90. The hydrogen bomb uses a small atomic bomb to trigger the reaction. The atomic bomb is essentially a fission reaction in which uranium-235 (U-235) is bombarded by neutrons. A simplified scheme of the reaction may be represented by the following equation, where a neutron *(n)* bombards U-235, thereby releasing fission fragments *(f.f.)* and 2.5 neutrons, each containing two million electron volts *(19k)*.

$$n + \text{U-235} \rightarrow f.f. + 2.5n \text{ (2.0 Mev each)}$$

In the initial blast there are about 170 fission fragments produced, of which one is krypton-90, the radioactive precursor to Sr-90. The decay of Kr-90 to Sr-90 occurs by the successive elimination of beta (β) particles. The Sr-90 formed then decays further by eliminating β particles until stable zirconium-90 is formed.

$$\underset{\text{krypton}}{{}_{36}\mathrm{Kr}^{90}} \xrightarrow[33\text{ sec.}]{-\beta} \underset{\text{rubidium}}{{}_{37}\mathrm{Rb}^{90}} \xrightarrow[2.7\text{ min.}]{-\beta} \underset{\text{strontium}}{{}_{38}\mathrm{Sr}^{90}}$$

$$\underset{\text{strontium}}{{}_{38}\mathrm{Sr}^{90}} \xrightarrow[28\text{ yr.}]{-\beta} \underset{\text{yttrium}}{{}_{39}\mathrm{Y}^{90}} \xrightarrow[65\text{ hr.}]{-\beta} \underset{\text{zirconium}}{{}_{40}\mathrm{Zr}^{90}}$$

The time indicated below each arrow is the half-life of that element and represents the time for one-half of a given quantity of the element to decay. The long half-life of 28 yr. for Sr-90 is one of the properties that make it a problem in long-term fallout. Y-90, the daughter of Sr-90, eliminates a β particle prior to forming stable Zr-90. Its half-life is only 65 hr.; thus, the radioactive effects of Sr-90 are actually due to the combined disintegrations of Sr-90 and Y-90 to stable Zr-90 *(1, 19k)*.

There are four natural isotopes of strontium, Sr-84, Sr-86, Sr-87, and Sr-88, all of which are nonradioactive *(19o)*. In the fission reaction six isotopes of strontium are produced, all of which are radioactive. Three of these have extremely short half-lives and are of no practical concern. The other three, Sr-91, Sr-90, and Sr-89, all decay to Y-90 and, finally, to Zr-90 which is stable. Sr-91 has a half-life of 10 hr. and Sr-89 has a half-life of 53 days. These two are of little concern in studies on long-term fallout because of their short half-life, and their decay product, Y-90, is not absorbed readily by the digestive tract.

Other principal isotopes of biological interest produced in the fission reaction are summarized in Table 1, and their occurrence as a function of time after the initial blast is given *(19m)*. The radioactive isotopes of iodine can be concentrated readily by the thyroid, but are of little importance in long-term fallout, since their half-lives are very short. The half-life of I^{131} is eight days. The rare

TABLE 1

Principal biological isotopes from slow neutron fission of 1 kg. of U-235 (19m)

Time after fission	Isotope	% Total activity
1 day	I-133	7.3
	Sr-91	6.7
	Ce-143	6.7
	I-135	5.7
	I-131	0.9
20 days	Ba-140	12.0
	Ce-141	9.7
	I-131	5.6
	Sr-89	5.0
	Ce-144, Pr-144	2.6
1 yr.	Ce-144, Pr-144	52.8
	Sr-89	2.7
	Sr-90, Y-90	3.7
20 yr.	Sr-90, Y-90	48.0
	Cs-137, Ba-137	45.0

earths, such as cerium^{144} and praseodymium, are not absorbed from the gut and also are very poorly taken up by plants. Barium^{140} is not a problem, since its half-life is only 13 days.

Cesium^{137} (Cs^{137}) is related chemically to potassium and is distributed in the body somewhat like potassium *(1, 19a)*. That is, it is found in muscle tissue, blood, and other soft tissues. Cs^{137} has a half-life of 27 yr., while its daughter, Ba^{137}, has a half-life of 2.6 min. Because of its long half-life, Cs^{137} would be a potential danger to the body, but fortunately it is removed fairly rapidly. The biological half-life in the body is 200 days. Another factor lessening the absorption of Cs^{137} in man is that plants take up little cesium from the soil colloidal complex.

The pathway of Strontium-90 into man. Sr-90 is potentially the most dangerous nuclide to man that is formed in the fission reaction. Studies on the geographical distribution of the Sr-90 blown into the atmosphere indicate that the majority has remained in the temperate zone of the northern hemisphere *(10,19e)*. Sr-90 has a long physical and biological half-life and is produced in relatively high yields in the fission reaction. The Sr-90 formed probably combines with oxygen to form $Sr^{90}O_2$, which gradually settles onto the earth's surface. It has been estimated that it takes 7–10 yr. to settle out one-half of the amount of Sr-90 formed from a blast *(10, 14)*.

Chemically, strontium and calcium are similar, since they are in the same group of the periodic table, but physically they differ, since strontium is about two and one-half times as heavy as calcium. There are several discrimination steps against the uptake of Sr-90 in its passage from the atmosphere to the bones of man and, apparently, this is due to the differences in physical properties of the two elements.

The Sr-90 deposited on the earth either remains on vegetation which may be eaten by animals or is washed into the soil. That which is washed into the soil is bound to the colloid complex similarly to calcium and is retained in the top few inches, thus being readily available to short-rooted plants. Plants discriminate against Sr-90 by absorbing it about 0.7 times as fast as calcium if sufficient calcium is available *(5, 15)*. When plants are eaten by animals, a portion of the Sr-90 absorbed is deposited rather permanently along with calcium in the bone, though at a somewhat slower rate than calcium. This deposition occurs mainly at sites of active bone growth and bone tissue replacement. Sr-90 can also be passed from the blood stream into a developing fetus and into milk.

Since Sr-90 and calcium metabolism are closely associated, concentrations of Sr-90 are generally expressed in terms of calcium. The most common unit used is the Sunshine Unit (S.U.), which is equal to the number of micromicrocuries of Sr-90 per gram of calcium (see Appendix). It is important to note that the Sunshine Unit represents the ratio of Sr-90 to calcium present. In itself it is not an absolute amount of Sr-90, although it is often used in this sense by assuming that the calcium level in the body is 1,000 g.

Estimated values of the discrimination against Sr-90 in the passage from plant to man vary, according to the investigator. Most authorities estimate that the discrimination factor for cow's milk is about 0.09 to 0.14; that is, that there are seven to 11 times more Sunshine Units present in the cow's ration than appear in the milk *(5, 8, 15, 19o)* (see Appendix for Discrimination Ratio definition). Studies in rats and rabbits indicate a discrimination ratio of about 0.5 between the mother's blood and the fetus *(5, 19l)*. The rato of Sr-90 to calcium present in the milk of lactating goats was found to be 0.38 of that present in the blood *(19a, 22)*. It should be noted that discrimination factors or ratios may be expressed either as whole numbers or as their reciprocal fractions.

In the animal, the principal sites of discrimination are the gut, kidney, placenta, and mammary gland. Neuman *(19l)* has schematically summarized the discrimination scheme in the body and uses a factor of two for each site. This scheme is shown in Figure 1. The discrimination by the gut is apparently

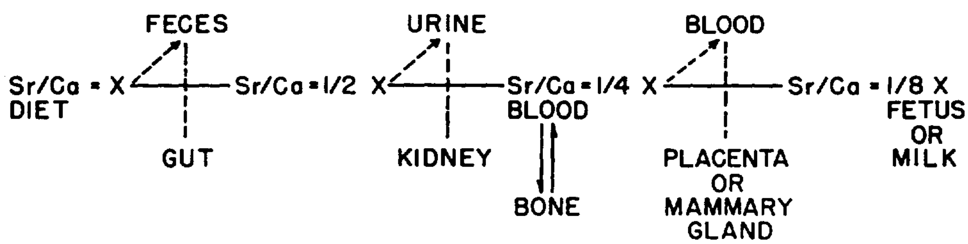

FIG. 1. Schematic summarization of major discrimination sites against Sr-90. A discrimination factor of two is assumed for each site *(19l)*.

influenced somewhat by the diet. It has been reported that if the diet is primarily milk the discrimination by the gut is lowered *(5, 19l)*. The discrimination ratio from diet to bone shows considerable variation, but the more recent work indicates a value of four *(8, 15)*.

These discrimination values indicate that the Sr-90 content of milk per gram of calcium should be less than vegetables or cereals, because of several discrimination sites, and also less than other animal foodstuffs because of the additional discrimination by the mammary gland. However, the possibility that human and animal foods differ in their Sr-90 content and that the human gut does not discriminate as well against Sr-90 on a diet high in milk must also be considered in any evaluation. This will be considered more fully later.

The levels of Sr-90 in milk. Apparently, it has been only since April of 1954 that milk has been routinely analyzed for its Sr-90 content. These analyses are under the supervision of the Atomic Energy Commission and are a part of Project Sunshine. One of the aims of Project Sunshine was to find an index by which the Sr-90 levels in human bone could be readily estimated. Milk and its products were a natural choice, since in the United States the majority of the dietary calcium comes from milk products and, thus, the levels in milk should parallel those found in human bone. If the discrimination factor from milk to bone and the Sr-90 level in milk is known, the Sr-90 content in human bone can be readily estimated. Also, the monitoring of milk is facilitated by the fact that fairly representative samples are easy to obtain from different parts of the United States and the world. It is chiefly for these reasons that the general public has become more aware of Sr-90 in milk than in other food products.

Procedures for analyzing Sr-90 are generally long and tedious and are subject to considerable variation. The common method used is to ash the sample, dissolve it in hydrochloric acid and add a carrier of radioactive yttrium, which is subsequently precipitated as the oxalate and counted in special low-level counters *(23)*. Since there is some experimental error, the values reported may not be absolute and some caution must be used in interpreting data. The present level of Sr-90 in milk which gives only 10–15 disintegrations per quart per minute *(23)* illustrates the difficulties in making such low-level counts.

Since April of 1954 in the United States, monthly analyses of Sr-90 in milk samples from six major milk sheds have been made for periods ranging from

TABLE 2

Sr-90 content of dried milks (19e)

Date	Location							
	Perry, New York	State College, Miss.	St. Louis, Mo.	Columbus, Wis.	Mandan, North Dakota	Portland, Oregon	Japan	United Kingdom
	(Sunshine units)							
1954—April	0.47	......	......	......	......	......	......	......
May	1.2	......	......	......	......	......	......	......
June	1.3	......	......	......	......	......	......	......
July	1.5	......	......	......	......	......	......	......
August	1.2	......	......	......	......	......	......	......
Sept.	1.5	......	......	......	......	......	......	......
Oct.	1.4	......	......	......	......	......	......	......
Nov.	1.1	......	......	......	......	......	......	......
Dec.	0.64	......	......	......	......	......	......	......
1955—Jan.	2.5	......	......	......	......	......	3.0	......
Feb.	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	......
Sept.	1.5	3.2	......	3.3	4.7	......	2.0	......
Oct.	2.8	......	......	4.4	6.9	......	7.5	......
Nov.	2.5	......	......	3.7	7.4	......	2.5	......
Dec.	3.3	......	......	3.0	10.0	......	3.5	......
1956—Jan.	2.3	......	......	3.0	3.5	......	2.7	4.0
Feb.	2.0	......	......	3.5	8.1	......	......	......
March	2.0	6.3	......	3.4	11.0	......	3.5	......
April	2.9	6.7	......	3.4	9.6	5.2	3.0	4.6
May	2.8	4.9	......	2.8	17.0	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	......	......	......
Sept.	4.9	4.8	......	4.3	10.7	......	2.7	......
Oct.	5.4	......	......	4.72	8.9	......	......	......
Nov.	5.6	......	......	......	3.6	......	......	......
Dec.	......	......	......	......	......	......	......	......
1957—Late *(11)*	4.5	......	6.5	5.5	10.0	7.0	......	......

1 to 4 yr. These analyses were made on dried milk samples that were obtained at local plants. In January of 1955, intermittent analyses were carried out for Sr-90 in milk obtained from Japan and the United Kingdom (primarily England). The results of these analyses until December, 1956, are presented (Table 2) and are expressed in Sunshine Units *(19e)*. The most recent summary of the average Sr-90 content of dried milk from various parts of the world as of late 1957 are also tabulated in Table 2 *(11)*.

These data show that there has been an increase in the Sr-90 content of milk in different parts of the world. The 1956 values (Table 2) for Japan appear low when compared to the previous values in the table, but this is probably due to the fact that only a few samples were analyzed in 1956. The amount of Sr-90 in dried milk for Mandan, North Dakota, is high in comparison with other areas of the United States and is apparently due to the deficient levels of calcium in the soil of that region. As a result, the deposited Sr-90 is absorbed more efficiently by plants.

There are few data available on the Sr-90 content of fresh milk, though a study has been carried out in the Chicago area *(19j)*. Samples of fresh milk were obtained monthly from several large Chicago dairies from March, 1955, to March of 1956. The milk samples were analyzed for Sr-90 and the results are presented (Figure 2). The curve in Figure 2 shows a maximum from June to

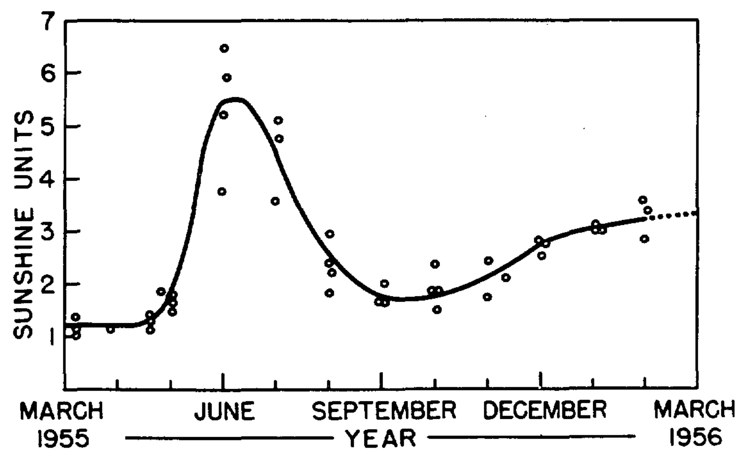

FIG. 2. Monthly fluctuations in Sr-90 content of fresh milk in Chicago *(19j)*.

August in 1955, followed by a minimum and then a gradual rise to about 3 S.U. at the end of 1956. This is in agreement with the Columbus, Wisconsin, value of 3.4 S.U. at the end of 1956. The peak in the curve may be attributed to the fact that there was a heavy series of tests at Nevada that spring and when the cows were pastured on unplowed fields they received an increased level of Sr-90 from surface contamination of the plants. The level of 1–2 S.U. in March and April of 1955 was apparently due to the fact that the cows were eating stored feed which had been grown the previous summer.

Comparison of Sr-90 levels in milk with other foods. There has been approximately a fourfold increase in the average world Sr-90 content of milk from 1954 to the level of 5–6 S.U. in 1958. Unfortunately, the present data on the Sr-90 content of other foods are limited, but they are gradually being collected through the efforts of Project Sunshine and other agencies such as the U. S. Public Health Service. Fish have an extremely low Sr-90 level because of the low concentration of Sr-90 in the oceans, caused by dilution. Meat and eggs (not including the shells) contain little calcium and thus little Sr-90. Vegetables contain Sr-90 and an average value in Sunshine Units for various market frozen vegetables in 1956 was about twice that found in milk *(8, 11)*. Data on cereals also are meager, but apparently their levels of Sr-90 in Sunshine Units average about two and one-half times that of milk. In general, the level of Sr-90 in vegetables and cereals consumed by humans would be expected to be lower than the levels found in the same materials consumed by animals. Human foods are generally processed and surface contamination is largely removed. Furthermore, vegetables and, to some extent, cereals for human consumption are usually grown on well-fertilized, carefully cultivated soils; whereas, animals generally consume forage grown on less carefully maintained soils.

The 1957 level of about 5 S.U. of Sr-90 in milk suggests that the average level of Sr-90 in the ration of the dairy cow was about 40–50 S.U., because of the apparent discrimination factor of 7-11 *(19h)*. The average cow producing market milk in the United States receives supplements of rock calcium phosphates containing a low level of Sr-90 and/or animal bone meal containing about 5–10 S.U. Since this is discriminated against by a factor of 7–10 in passing to the milk, it is apparent that the present level of Sr-90 contributed by the succulent plants, grain, cereals, etc., consumed by the cow must be quite high. Data on this point are limited and show wide variations. Levels of Sr-90 found in cereals, vegetables, other plant sources, and water are shown in Table 3. The

TABLE 3
Sr-90 content of various human and animal plant sources

Source	Reference	Year	Location	Sr-90 Level Range	Sr-90 Level Average
				—(*Sunshine units*)—	
Vegetables (frozen)	*(8)*	1956	U.S.	1–21	7
Vegetables (frozen)	*(11)*	1957	U.S.	1–29	9
Wheat	*(11)*	1956	U.S.	9–38	23
Oatmeal	*(11)*	1956	(?)		6
Rice	*(17)*	1956	Japan	81–250	150
Rice	*(11)*	1956	(?)		4
Flour	*(11)*	1956	U.S. (Ill.)		6
Bran	*(11)*	1957	U.S. (Mich.)		9
Bean plant (parts)	*(19f)*	1956–7	U.S. (Md.)	4–81	45
Pea plant (parts)	*(19f)*	1956–7	U.S. (Md.)	19–39	30
Alfalfa	*(19j)*	1955	U.S. (Ill.)	3–38	18
Grass (normal soil)	*(19b)*	1956	England.	23–85	40
Grass (acid soil)	*(19b)*	1956	England	113–2,180	370
Hay	*(19c)*	1955	England	6–53	30
Drinking water	*(11)*	1956–7	U.S. (N.Y.)		0.1[a]

[a] About 0.1 $\mu\mu c$. of Sr-90 per liter. Based on consumption with 1 g. of Ca in diet per day.

data suggest that plant foods prepared for human consumption do contain a lower Sr-90 content than do plants consumed by animals.

From the incomplete data available, it is difficult to assess average values for the levels of Sr-90 present in various foods consumed by humans, though one can make some guesses on relative levels. Kulp and Slakter *(11)* have evaluated the Sr-90 intake of humans in the United States in late 1957, using as a standard a level of 6 S.U. in milk, 10 S.U. in vegetables, and 15 S.U. in cereals. They calculated an average Sr-90 intake of 6.5 S.U. for a person in the United States. Using these values, and knowing the source of dietary calcium, it is then possible to estimate the average Sr-90 intake of people in the various countries of the world. Any such estimation suffers, since specific data on the level of Sr-90 in the food in each country are not available and the effect of the total calcium level in the diet has not been well-defined *(18)*. However, such a calculation does show the effect a shift in eating habits could have on the relative Sr-90 intake of a population.

The various countries of the world, because of their differences in diet, receive a different percentage of their dietary calcium from cereals, vegetables, milk, and other minor products such as fish, meat, eggs, etc. The sources of calcium in national diets for a few representative countries are tabulated in Table 4 *(8)*.

TABLE 4

Sources of calcium in national diets (8)

Country	Cereals	Vegetables	Meats, eggs, fish	Milk products
	(% total calcium intake)			
Sweden	4	6	4	87
United States	4	5	7	85
France	8	12	5	75
Italy	19	14	5	62
Peru	17	37	5	41
Portugal	26	35	9	30
Japan	46	25	11	18

Twenty-one of the 35 countries listed by Eckelman *et al.* *(8)* receive more than 70% of their dietary calcium from milk products. The countries selected in Table 4 illustrate the large differences in the source of dietary calcium. If the following Sr-90 levels are used, based on milk as 6 S.U., vegetables as 10 S.U., and cereals as 15 S.U., and the small contribution from other foods is ignored, then the relative total amount of Sr-90 received in the diet, as well as the per-

TABLE 5

Estimated source of dietary Sr-90 for various countries

Country	From cereals	From vegetables	From milk products	Sr-90 in total diet
	(% total Sr-90 intake)			*(Sunshine units)*
United States	9.7	8.1	82.2	6.2
Italy	35.8	17.6	46.6	8.0
Portugal	42.4	38.0	19.6	9.2
Japan	65.9	23.8	10.3	10.5 (73)[a]

[a] On basis of 1956 rice crop *(17)*.

centage from each source, can be calculated. Results of this calculation are tabulated (Table 5).

The countries chosen for the calculations in Table 5 have greatly different sources of dietary calcium. For example, people in the United States receive 82% of their dietary Sr-90 from milk products but, in fact, have the lowest level of Sr-90 in Sunshine Units in their diet. The two extremes are the United States and Japan. Only 10% of the calcium in the Japanese diet comes from milk products. On the basis of this calculation, the total intake of Sr-90 for Japan is about two times that of the United States, because of the high level of cereals consumed and, in fact, may be many times higher, since the cereal consumed is largely rice, which has a short-root system *(17)*.

It is apparent that if, by some means of adverse advertising and ignorance on the part of the public, the calcium diet of the United States were shifted away from milk to cereal or vegetable products the population would be increasing the relative level of Sr-90 in their diet.

Influence of a milk diet on discrimination. The reason why a diet high in milk products contains less Sr-90 than other foods is because of the additional discrimination factors operating in its formation. The data in Table 6 represent dietary Sr-90 and not that finally deposited in the bone. There is evidence to indicate that as the ratio of milk in the diet increases the discrimination against Sr-90 in the passage across the gut decreases *(5, 6, 7, 12, 20, 21)*. It is known that certain materials increase calcium absorption, and milk is noteworthy in this regard. Comar *et al.* *(5, 12, 20)* have shown that specific substances, such as lactose, lysine, and arginine, which tend to increase calcium absorption, are even more effective in increasing strontium absorption. Thus, the normal discrimination from the diet to bone is about four, but on a milk diet may approach two *(5, 6, 7, 12)*. Rather conclusive evidence on this point is available for the rat, although the proportion of milk in the diet of these studies was much higher than would be present in a normal human's diet. The data concerning humans are not so convincing. Such studies generally have involved Sr-89, and a limited number of individuals who were hospitalized with advanced serious carcinomas; all of these subjects did not show less discrimination against strontium on the milk diet.

Kulp *et al.* *(8, 11)* use the discrimination factor of four between diet and bone for individuals in the United States. This value is based on the actual observed difference between the average level of Sr-90 in the diet of persons of varying ages in the United States and the actual level found in bone *(8)*. Again, these data are limited, because of the lack of data on normal diets. The reasons for a discrepancy between the limited laboratory experiments of Comar *et al.* *(5, 6, 7, 12)* and the actual observed values of Kulp *et al.* *(8, 11)* are not known. It may be that such data from rats can not be extrapolated to humans and that the limited studies with humans are in error. It is more likely, however, that the form in which milk and milk products are consumed regulates the discrimination factor. Lactose was the most powerful calcium and strontium absorption agent found by Comar *et al.* *(5, 12, 20)*; yet, many dairy products consumed by humans,

TABLE 6

Radiation received by humans from various sources

Source	Milliroentgens per yr.	Equivalent sunshine units	Reference
External radiation:			
Background—granitic rock			
Sea level	147		*(13)*
5,000 ft.	170		*(13)*
10,000 ft.	230		*(13)*
Background—sedimentary rock			
Sea level	80		*(13)*
5,000 ft.	103		*(13)*
10,000 ft.	163		*(13)*
Background—open oceans	57		*(13)*
Wrist watch	10–40		*(13, 19g)*
X-ray (routine chest)	500–2,000		*(19g)*
X-ray (anterior-posterior body)	3,000		*(13)*
X-ray (lateral body)	7,000		*(13)*
Brick house	25–50		*(14)*
Earth fallout from nuclear detonations in 1956	1–5		*(14, 19g)*
Soft tissue internal radiation:[a]			
Potassium-40	19		*(13)*
Radium	2		*(19g)*
Carbon-14	1.5		*(13)*
Cesium-137	1		*(19g)*
Equivalent internal bone radiation:[b]			
Radium	6.7, 120	2.2, 40	*(13, 14)*
Potassium-40	5	1.7	*(19g)*
Cosmic rays—Sea level	37	12	*(14)*
5,000 ft.	60	20	*(14)*
10,000 ft.	112	37	*(19g)*
Strontium-90[c]			
Now (1957-8):			
Children	1.5	0.5	*(14)*
Adults	0.6	0.2	*(11)*
In 10 yr. if testing stops now:			
Children	4.8	1.6	*(11)*
Adults	1.2	0.4	*(11)*
If testing continues:[d]	12–63	4–21	*(11, 14)*

[a] In addition to external radiation, much of which penetrates tissue.

[b] External radiation (chiefly γ) other than cosmic rays also is active at the bone level. It is difficult to assess the proportion that actually is. Dudley and Evans *(19d)* assume that about 70% of the radiation from the ground rocks is effective at the skeletal level.

[c] Eckelman *et al. (8)* estimate that the standard deviation for Sr-90 in individual persons will be about 40% of the mean at equilibrium.

[d] Value at 50 yr. if testing continued at same rate with same type devices as past 5 yr. New Sr-90 entering atmosphere is in equilibrium with that falling out.

such as cheese, cultured milks, etc., contain a negligible amount of lactose. Furthermore, milk and milk products are generally consumed in conjunction with other foods, where the effect may be minimized.

The immediate need for further investigations in this area is apparent. Conclusive data are needed concerning the discrimination against Sr-90 in humans on a milk diet and concerning the effect of specific dairy products. If it is true that certain dairy products, or the way in which they are consumed, do not allow the gut to discriminate as well against Sr-90, then it would be preferable if the dairy industry itself would find out the facts about them. It would be undesirable to let someone else not directly concerned with the industry throw a cloud of suspicion over certain dairy products, with opinions based on incomplete studies. At the very least, the conflicting data relative to the average discrimination against Sr-90 in the whole population on a milk-containing diet need to be resolved immediately.

Danger of radioactivity in foods. The question of the extent to which ionizing radiations are harmful to man has received considerable attention by many investigators and as to date the results are generally inconclusive *(2, 9, 14, 16, 19g)*. Some believe that all radiation, regardless of dosage, is harmful and cumulative; others believe that a threshold level must be reached at any given time before there is any biological damage. Biological damage can be caused by high levels of radiation and it is postulated that the ionization caused by radiation leads to the formation of powerful oxidizing radicals. One of the most important consequences of this is enzyme and other protein alteration, either by oxidation of sulfhydryl groups or protein denaturation. The effect of ionization on ribo- and desoxy-ribonucleic acids is shown by a reduction in nucleic acid synthesis and a reduction in total but an increase in abnormal mitoses depending on the dosage received.

The debate between various authorities over the effects of low-level radiation arises because measurements are difficult to make. The effects of large doses of radiation are most apparent and they affect first the hematopoietic or blood cell-forming system. The germ cells also are quite sensitive, as are the cells of the intestinal mucosa. Bone, liver, and brain cells are less affected by large doses of radiation. It is postulated that long-term, low-level radiation may cause increased tumors of many types, including bone cancer, leukemia, and shortening of the life span.

Investigations with small animals have indicated that their life span is shortened when exposed to high levels of radiation. If such data are extrapolated to humans (there is no direct evidence that such an extrapolation is valid), then the presently accepted life-time maximum dose from all sources of 100 roentgens (r) over a period of 70 yr. would reduce man's life span by 500 days *(19g)*. Estimates have also been made by life insurance companies for the reduction of a 70-year life span by various natural habits: for example, 25% overweight, −3.6 yr.; 1 package of cigarettes per day, −7.0 yr.; driving a car in the United States, −400 days *(19g)*. If these data are valid, then the present accepted life-time dose would not reduce life span any more than accepted practices.

Humans receive radiation from many sources besides Sr-90. Cosmic rays, radium present in earth, bones, wrist watches, etc., potassium^{40} and cesium^{137} present in earth, foods, and tissues, x-rays, and other sources all contribute to the total dosage received. Such radiation sources are listed (Table 6). External radiation amounts to about 150 milliroentgens (mr) per year, with wide variations in the population. Altitude and radiation from the ground account for some of the largest variations. A dosage of 150 mr per year is equivalent to about 10 r of radiation in a 70-yr. life span, or 10% of the present accepted maximum life-time dosage.

In making comparisons of radiation sources, it must be taken into account that Sr-90 radiation is localized in the bone and all of the other sources of external radiation can not be compared directly because of differences in penetrating power. However, Libby *(14)* has pointed out that it is possible to compare directly Sr-90 and cosmic ray radiation at the bone level. The β-particles eliminated by Sr-90 and Y-90 decomposition have a tissue penetration of about 2 mm. and this is localized in the bone where cell formation is taking place. On the other hand, cosmic rays penetrate the whole body, and the ionization density along the tracks of the μ-mesons, which are the principal cosmic ray components to consider in the lower air, is similar to that of the Sr-90 and Y-90 decomposition. Hence, it is possible to equate cosmic-ray dosage and Sr-90 dosage directly, and express cosmic ray radiation in terms of Sunshine Units. Libby *(14)* notes that the annual cosmic-ray radiation dosage at Washington, D. C. (or any place at sea level at this latitude) is about 37 mr per year and at Denver, Colorado (5,000 ft.), 60 mr per year. This is equal to about 23 mr per year difference, or is equivalent to 8 S.U. (1 S.U. is about the same as 3 mr per year). The present level of Sr-90 in the bones of children is between 0.5 and 1.0 S.U. and, if testing were to continue at the same rate indefinitely to equilibrium, the level of Sr-90 in human bone would be in the range of 4–21 S.U. *(8, 11, 14)*. This level compared to 8 S.U. derived from cosmic rays at Denver over Washington, suggests that if the level were strong enough to cause leukemia and bone cancer there should be a correlation of such diseases with altitude. Examination by Libby of Public Health records showed that this is not the case *(14)*.

It is apparent that the present levels of Sr-90 in bone are contributing a small amount of radiation compared to other sources. If testing were to continue for the next 50 yr. at the same rate, the contribution from Sr-90 in bones would be about equivalent to moving from sea level to 5,000 ft. altitude.

At present, the maximum permissible dose of Sr-90 in bone is 100 S.U. for the average population. The present average level in children is less than 1% of this and will rise only to 4–20% of this, at the extreme, if testing continues. One should also not underestimate the abilities of the atomic scientists. Since it is the U-235 of the atomic bomb detonator which produces Sr-90, and not the hydrogen bomb itself, the development of a "clean" means of starting the hydrogen bomb would lower or eliminate Sr-90 formation. The radiation produced from a hydrogen bomb is chiefly due to tritium, which is an extremely weak β particle emitter. Attempts are now being made to develop such a system.

Genetic effects of radiation. While this review has been concerned chiefly with the significance of Sr-90 in milk, it is unwise to neglect the genetic considerations of the fallout problem. This is necessary because there is not a clear division point between the various phases of the fallout problem. As a source of radiation to the gonads, the Sr-90 derived from food and present in bone is of small consequence because of the low level present and the short penetrating power of the β particles. However, the fallout of other isotopes produced in the fission reaction has increased the background radiation. Although this increase is quite small (see Table 6), at present the greatest debate over the continuation of nuclear tests centers around the genetic effects this increased radiation may have on future generations. These effects are extremely difficult to evaluate since so little is known about human genetics. Judging from experience with plants, insects, animals, and other lower organisms, there is every reason to expect some genetic effects of radiation. It seems likely that a major portion of the spontaneous mutations of the human species is not due to radiation but to other causes. Muller [quoted by Libby *(14)*] has estimated that 10% of the spontaneous mutations in the human species may be due to irradiation. If one estimates that the 150 (mr) per year from natural radiation now causes 10% of the spontaneous mutations, then the test fallout, if continued indefinitely at the present level would cause an increase in the over-all natural spontaneous mutation rate of about 0.2% *(14)*. This effect is comparable to moving to a slightly different locality and is much less serious than changing houses or doing any one of a dozen different things *(14)*.

At present in the United States some 80,000, or 2%, of the four million children born alive each year have some tangible genetic defects *(2)*. The increase expected, if estimates and extrapolations to low levels are justified and the tests continue, would be about 160 children per year at the 0.2% level *(2)*. Whether this effect can be considered small compared to unavoidable damage caused by spontaneous mutations and other presently accepted hazards of life depends on ethical and emotional differences in individuals. We as a country accept death and maiming through preventable accidents such as those from jobs, sports, automobiles, etc. We discount the harm by considering the advantages. Also, the individual believes he can exercise some control over them. The fallout hazards are beyond the control of the individual, involve his descendants, and so have a strong emotional impact. The need for further controlled studies in this area is apparent. From the evidence at hand, one must conclude that the present and projected increases in radiation due to nuclear detonations, if testing is continued at the same rate, are small enough so that they should not cause us undue concern until further facts concerning humans are available.

APPENDIX

Common Radioactive Terms

1. *Curie (c):* The absolute unit of radioactivity equal to 3.7×10^{10} disintegrations per second. The microcurie (μc) is equal to 3.7×10^4 dps. *(4)*.
2. *α-Particles:* Nuclei of helium atoms with high ionization power but low penetrating power.

   β-Particles: Electrons traveling at high velocities with better penetrating but less ionization power than α-rays.

   γ-Rays: Light or x-rays with high penetrating power and comparable biologically to β-rays in ionization power.
3. *Roentgen (r):* A quantity of radiation such that the associated corpuscular emission per 0.001293 g. of air produces, in air, ions carrying one electrostatic

unit of quantity of electricity of either sign. The roentgen is a measure of energy absorbed and corresponds to the absorption of 83 ergs/g of air and about 93 ergs/g of tissue *(4)*.

4. *rep:* Physical equivalent of a roentgen and equals 93 ergs/g *(4)*.
5. *rad:* A unit of absorbed dose which is equal to 100 ergs/g *(4)*.
6. *RBE:* Relative Biological Effectiveness. RBE compares the biological effectiveness of radiation from different sources. For β particles and γ rays, RBE = 1; for α particles, RBE = 20, and for protons, RBE = 10. This unit is not precise, for it depends on pH, oxygen tension, and the organ radiated *(19k, 19n)*.
7. *rem:* It is the unit of RBE dose. That is, it includes the RBE and the absorbed dose in rads. This unit also has a degree of uncertainty *(19n)*.
8. *Discrimination ratio:* The ratio of strontium to calcium in any product compartment decided by the ratio in a precursor compartment. Comar *et al.* *(5)* express it as the "Strontium-Calcium Observed Ratio": $OR_{sample\text{-}precursor} = \dfrac{\text{Sr/Ca of sample}}{\text{Sr/Ca of precursor}}$. For example, an $OR_{milk\text{-}diet}$ of 0.1 means that the diet of a cow contains ten times as much Sr-90 per unit of calcium as is found in the milk. This may also be expressed as a Discrimination Ratio, or Factor of 10.
9. *Sunshine Unit (S.U.):* A S.U. is equal to the number of micromicrocuries of strontium-90 per gram of calcium ($\mu\mu c$ Sr-90/g Ca) and is the common unit for describing the concentration of Sr-90 in man *(19n)*. It is equal to one-hundredth of the average permissible body burden of Sr-90 for the general public ($0.1\mu c$). Since the body contains about 1,000 g. of Ca, the maximum permissible amount of Sr-90/g Ca for the average population is equal to 1×10^{-4} μc Sr-90/g Ca. The Sunshine Unit is 1/100th of this value, or equal to $\mu\mu c$ Sr-90/g Ca.

REFERENCES

(1) ANDERSEN, E. C., SCHUCH, R. L., FISHER, W. R., AND LANGHAM, WRIGHT. Radioactivity of People and Foods. *Science*, **125**: 1273. 1957.

(2) ANONYMOUS. AEC Committee Views Fallout. *Chem. and Eng. News*, **35**: 49. 1957.

(3) CASTER, W. O. Strontium-90 Hazard: Relationship Between Maximum Permissible Concentration and Population Mean. *Science*, **125**: 1291. 1957.

(4) COMAR, C. L. *Radioisotopes in Biology and Agriculture*. McGraw-Hill Book Co., New York. 1955.

(5) COMAR, C. L., RUSSELL, R. S., AND WASSERMAN, R. H. Strontium-Calcium Movement from Soil to Man. *Science*, **126**: 485. 1957.

(6) COMAR, C. L., WASSERMAN, R. H., AND NOLD, M. M. Strontium-Calcium Discrimination Factors in the Rat. *Proc. Soc. Exptl. Biol. Med.*, **92**: 859. 1956.

(7) COMAR, C. L., WASSERMAN, R. H., ULLBERG, SVEN, AND ANDREWS, G. A. Strontium Metabolism and Strontium-Calcium Discrimination in Man. *Proc. Soc. Exptl. Biol. Med.*, **95**: 386. 1957.

(8) ECKELMAN, W. R., KULP, J. L., AND SCHULERT, A. R. Strontium-90 in Man. II. *Science*, **127**: 266. 1958.

(9) FAILLA, G., BUGHER, J. C., BURNETT, C. H., CANTRIL, S. T., GLASS, H. B., AND WARREN, S. Statement of Radioactive Fallout (by the Advisory Committee on Biology and Medicine of Sigma Xi). *Am. Scientist*, **46**: 138. 1958.

(10) KULP, J. L., ECKLEMAN, W. R., AND SCHULERT, A. R. Strontium-90 in Man. *Science*, **125**: 219. 1957.

(11) KULP, J. L., AND SLAKTER, RIETA. Current Strontium-90 Level in Diet in United States. *Science*, **128**: 85. 1958.

(12) LENGEMANN, F. W., COMAR, C. L., AND WASSERMAN, R. H. Absorption of Calcium and Strontium from Milk and Non-Milk Diets. *J. Nutrition*, **61**: 571. 1957.

(13) LIBBY, W. F. Dosage from Natural Radioactivity and Cosmic Rays. *Science*, **122**: 57. 1955.

(14) LIBBY, W. F. Radioactive Fallout. *Proc. Natl. Acad. Sci., U. S.*, **43**: 758. 1957.

(15) NEUMAN, W. F. Uncertainties in Evaluating the Effects of Fallout from Weapons Tests. *Bull. Atomic Scientists*, **14**: 31. 1958.

(16) NEWCOMBE, H. B. Magnitude of Biological Hazard from Strontium-90. *Science*, **126**: 549. 1957.

(17) OGAWA, IWAO. Fallout and Rice Contamination in Japan. *Bull. Atomic Scientists*, **14**: 35. 1958.

(18) PALMER, R. F., THOMPSON, R. C., AND KORNBERG, H. A. Effect of Calcium on Deposition of Strontium-90 and Calcium-45 in Rats. *Science*, **127**: 1505. 1958.

(19) The Nature of Radioactive Fallout and Its Effects on Man. Hearings Before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy of the Congress of the United States. U. S. Govt. Prtg. Office, Washington, D. C. 2,065 pp. 1957.

(19a) ALEXANDER, LYLE. *Ibid.*, 508.

(19b) BOOKER, D. V., BRYANT, F. J., CHAMBERLIN, A. C., MORGAN, A., AND SPICER, G. S. *Ibid.*, 1722.

(19c) BRYANT, F. J., CHAMBERLAIN, A. C., MORGAN, A., AND SPICER, G. S. *Ibid.*, 1709.

(19d) DUDLEY, R. A., AND EVANS, R. D. *Ibid.*, 1236.

(19e) EISENBUD, A. M. *Ibid.*, 554.

(19f) HARLEY, J. H., HARDY, E. P., WHITNEY, I. B., AND EISENBUD, A. M. *Ibid.*, 591.

(19g) JONES, H. B. *Ibid.*, 1100.

(19h) KULP, J. L. *Ibid.*, 676.

(19i) LIBBY, W. F. *Ibid.*, 1198.

(19j) MARTELL, E. A. *Ibid.*, 616.

(19k) MILLS, M. M. *Ibid.*, 24.

(19l) NEUMAN, W. F. *Ibid.*, 710.

(19m) REVELLE, ROGER. *Ibid.*, 523.

(19n) TAYLOR, L. S. *Ibid.*, 778.

(19o) WESTERN, F. *Ibid.*, 492.

(20) WASSERMAN, R. H., COMAR, C. L., AND NOLD, M. M. The Influence of Amino Acids and Other Organic Compounds on the Gastrointestinal Absorption of Calcium-45 and Strontium-89. *J. Nutrition*, **59**: 371. 1956.

(21) WASSERMAN, R. H., COMAR, C. L., AND PAPADOPOULOV, D. Dietary Calcium Levels and Retention of Radiostrontium in the Growing Rat. *Science*, **126**: 1180. 1957.

(22) WASSERMAN, R. H., LENGEMANN, F. W., AND COMAR, C. L. Comparative Metabolism of Calcium and Strontium in Lactation. *J. Dairy Sci.*, **41**: 812. 1958.

(23) WHITNEY, I. B. "Hot" Milk—Analysts Nightmare. *Chem. and Eng. News*, **35**: 45. 1957.

(24) WURM, ROSS. Is There Danger in Radioactive Milk? *Hoard's Dairyman*, **102**: 963. 1957.