natural sciences deal with the first, ethics with the second . . . the peculiarity of economics is that it is called upon to bridge this gap" (*15*).

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Radioactivity of People and Milk: 1957

Measurements of 2200 samples for cesium-137 and potassium-40 levels reveal interesting correlations.

Ernest C. Anderson

The investigations of the gamma activities of people and foodstuffs previously reported for 1956 (*1*), made by means of a large 4π liquid scintillation counter (*2*), have been continued (*3*). During 1957, dried milk was routinely sampled from 31 locations within the continental United States, and a few spot checks were made on foreign milks. A total of 887 measurements were made on milk. Studies on people included 820 determinations, mostly weekly measurements on a group of 14 control subjects, but 311 determinations on people from 30 states were included. Measurements on a total of 518 samples of dried blood from nine states completed the program. The entire series of 2200 measurements occupied about 20 percent of the operating schedule of the counter and was accomplished by one full-time and one half-time technician (including the data processing).

It is clearly impossible to present here a tabulation of all results or even to give the detailed graphs of activity versus time by states. The original data for 1956, 1957, and part of 1958 are tabulated in *HASL-42* (*4*). This article presents only the broad outlines of the results and indicates the principal correlations which are emerging.

As before, simultaneous measurements of both potassium-40 and cesium-137 were performed on all samples. The unit of measurement for the latter has been changed to micromicrocuries of cesium-137 per gram of potassium, to conform with general practice. Detailed gamma spectrum measurements made with the Los Alamos crystal spectrometer (*5*) have shown that these are the only significant gamma-emitting nuclides in this energy range normally present in people and milk. During periods of weapon testing, barium-140 appears prominently in milk, as previously reported (*6*), but we have not detected it in people. The electronic computation of the data as now programmed does not take barium-140 into account, and barium-140 is treated as if it were potassium-40. Because of the predictability of the potassium content of milk, it is feasible to calculate both barium-140 and cesium-137 from the data, and the programming is currently being revised to accomplish this. In the present article, however, all milk samples showing barium contamination are excluded from the average. The extent and duration of typical barium-140 contamination are illustrated in Fig. 1, which shows the yearly data for fresh milk samples from New Mexico. (Several sources are represented in these samples.)

The absence of barium-140 in people is indicated by Fig. 2, which shows the cesium-137 and potassium-40 activities averaged over 14 control subjects measured weekly. Barium-140 derived from the milk would have produced a rise in the apparent potassium-40 level (lower curve) during the summer months. The increase in cesium-137 level at this time reflects the corresponding increase in the milk supply.

The presence of iodine-131 in either people or milk would not constitute an interference, since the low energy gamma ray does not fall in the spectral bands accepted by the analyzers. The improved liquid scintillation counter now under construction will have additional energy channels for iodine-131 and for beta-ray bremsstrahlung.

Results

The frequency distribution of potassium-40 in the population sample is shown in Fig. 3. The average specific activity is 2.70 gamma rays per second and pound, corresponding to a potassium content of 1.98 grams per kilogram of body weight, or 139 grams of potassium in the 70-kilogram "standard man." The standard deviation of the normal curve is 14 percent. The average is not significantly different from the 1956 result (*1*), but the deviation is slightly less (the previous figure was 18 percent) and there is no tail on the upper end of the distribution, probably a result of better control over surface contamination.

The corresponding curve for cesium-137 is given in Fig. 4. The width of 36 percent is identical with the 1956 value. The possible significance of the very small difference in the average values (44 and 41 micromicrocuries of cesium per gram of potassium) is discussed below.

The cesium-137 data for people as a

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function of geographic location are given on the map (Fig. 5). In order to obtain statistically significant averages, the states were grouped regionally as indicated. To compare these data with those reported for 1956 (*1*), the latter cesium/potassium ratios should be multiplied by 80. Individual determinations are based on 200 seconds of counting time and, for the average subject, give a statistical precision of better than ± 3 percent on the potassium-40 and better than ± 4 micromicrocuries per gram on the cesium-137. Because of the much larger variations among individuals, the precision of the average is limited by the number of subjects and the adequacy of the sampling. If the sampling is assumed to be random (this is probably not the case because of the frequency of family groups among the subjects), the precision of the regional population averages could be estimated by dividing the standard deviation of the population curve (Fig. 4) by the square root of the number of persons represented in the average. On this basis, many of the differences evident in Fig. 5 are to be regarded as significant.

The 1957 levels of cesium-137 in milk samples from various parts of the United States are given in Fig. 6.

On the basis of the counting rate of a typical 50-pound NFDMS (Non-Fat Dry Milk Solids) sample and average background, the statistical precision resulting from 400 seconds of counting time for the sample and 400 seconds for the background is ± 0.51 percent for the potassium-40 and ± 1.1 micromicrocuries per gram of potassium for the cesium-137 determination. A series of 21 determinations on a control milk sample over the period October 1957 through February 1958 gave an observed random scatter corresponding to a standard deviation of ± 0.87 percent for the potassium-40 and ± 1.3 micromicrocuries per gram of potassium for the cesium-137. This indicates an error slightly larger than statistical for the potassium-40 and an essentially statistical error for the cesium-137. The results, of course, may reflect a considerably larger error on the absolute basis because of systematic errors in counter calibration, and so on.

Sampling points are concentrated in the West in order to encircle the Nevada test site as completely as possible and to take advantage of the fact that the most extreme variations of altitude and rainfall are to be found in this region. The 1958 sampling network has been expanded in the eastern United States to better delineate the indications of structure in the fallout pattern there. The absence of data from the High Plains and the Southeast is a result of the difficulty of obtaining dry milk samples from these areas.

The changes in levels of cesium-137 in the milk from a given locality throughout the year are indications of seasonal variation on which are superimposed transient peaks due to tropospheric debris from weapon tests. Data will be required for a period of several years for the analysis of the seasonal factors, so the averages here reported are based on the entire year, with the exception of those periods during which the presence of barium-140 indicated tropospheric contamination.

Only a limited number of foreign milk samples were analyzed in 1957, since the principal objective of the program was an intensive study of fallout mechanism rather than extensive monitoring. Single samples from England and Japan, respectively, both had a cesium-137 content of 25 micromicrocuries per gram of potassium. Both were produced late in 1956 and, while slightly lower in cesium-137 content, are not strikingly different from samples produced in the United States for this time. Five samples of dry milk from Argentina, produced in November and December 1956, gave an average cesium content of 9 micromicrocuries per gram of potassium, with a range of from 4 to 12. These are definitely lower than Northern Hemisphere values by a factor of about 4. Twelve monthly samples from Australia during 1957 did not indicate such a large hemi-

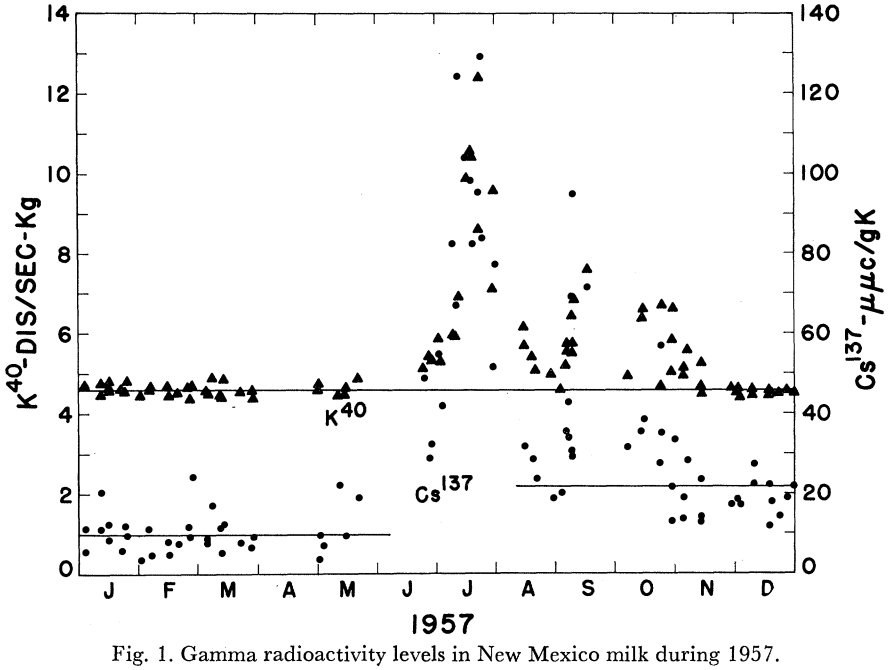

Fig. 1. Gamma radioactivity levels in New Mexico milk during 1957.

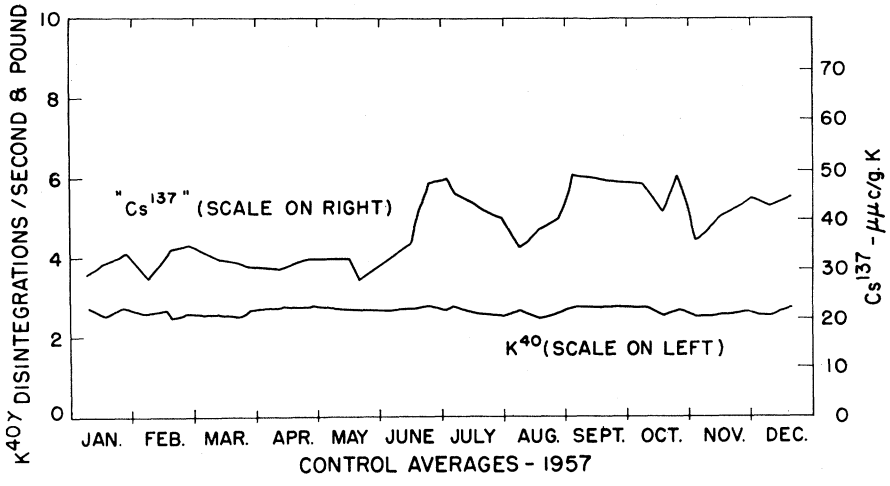

Fig. 2. Data for control subjects (1957).

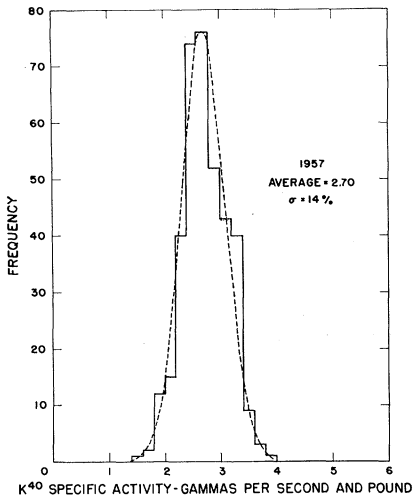

Fig. 3. Frequency distribution of potassium-40 activity in people (1957).

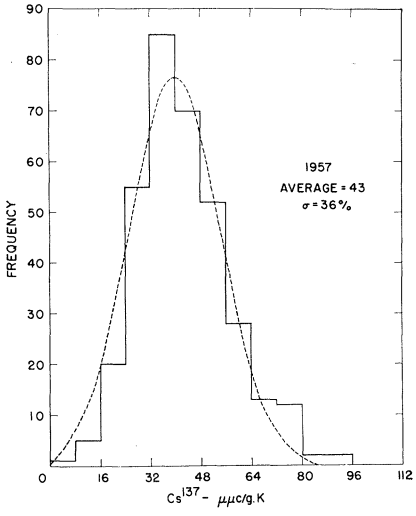

Fig. 4. Frequency distribution of cesium-137 activity in people (1957).

spheric effect, for they gave an average of 18 micromicrocuries per gram of potassium, compared with a range for samples from the United States of 20 to 40 for the same total rainfall. Because of seasonal and other fluctuations, care should be exercised in drawing conclusions from such a limited number of samples.

It was hoped that the dried blood samples would provide a simple and economical method of checking the radioactivity of meat. Unfortunately, this has not proved to be the case. Since the material is destined for use as fertilizer or animal food, it is not prepared under the carefully controlled conditions employed in the drying of milk and is subject to external contamination during processing. This is evidenced by the erratic variations in the activity levels and by the presence of such fission products as zirconium-95 and cerium-144. The latter are absent from the flesh of cows, even animals that have grazed near the Nevada test site, whose rumens show comparatively high levels of these activities (7). For this reason, none of the dried blood measurements are reported here.

Discussion

There appear to have been no striking changes in the cesium levels in human beings between 1956 and 1957. In Fig. 7, the concentrations in various regions, averaged over 1956, are plotted against the 1957 averages. The variations do not seem to be significant in view of the small population sample available. The consistency suggests that a rather stable fallout mechanism is operating and that a more detailed analysis should help illuminate this mechanism.

Table 1. Observed and estimated changes in levels of cesium-137 in people in the United States.

Year	Av. Cs level (μμc/g K)	Calculated according to alternative mechanisms	
		Integrated	Differential
1956	41 ± 1.3	(41) assumed	(41) assumed
1957	44 ± 1.1	68	50
Change	3 ± 1.7	27	9

A more sensitive analysis for a possible temporal change is possible if the entire United States population average is considered, because of the large sample size.

The average cesium/potassium ratio in the United States population was 41 micromicrocuries per gram during 1956 and 44 micromicrocuries per gram in 1957 (8). These averages were computed by first averaging over certain regions (shown on the map, Fig. 5) and then averaging the regions in order not to give undue weight to states such as New Mexico which are disproportionally represented in the population sample. The number of determinations was 134 in 1956 and 207 in 1957, if the New Mexico sample is reduced to the same size as the samples from other regions. If the standard deviation of the average of n determinations is assumed to be $1/n^{1/2}$ times the observed standard deviation of the population distribution curve (36 percent for both years), then the precision of yearly averages would be 3.1 percent and 2.5 percent, respectively. The difference between the two years is, therefore, 3 ± 1.7.

This difference can be compared with the increase expected on the basis of two extreme alternatives. First, assume that all the cesium in soil is unavailable to plants, so that the cesium is derived from direct fallout only. In this case, the cesium should vary as the fallout rate, and hence as the stratospheric inventory. The second alternative is that all cesium in the soil is available to plants, in which case the cesium in man should vary as the total integrated fallout. Intermediate cases are also possible.

Strontium-90 values can be used for the fallout data, if it is assumed that there is no gross fractionation between

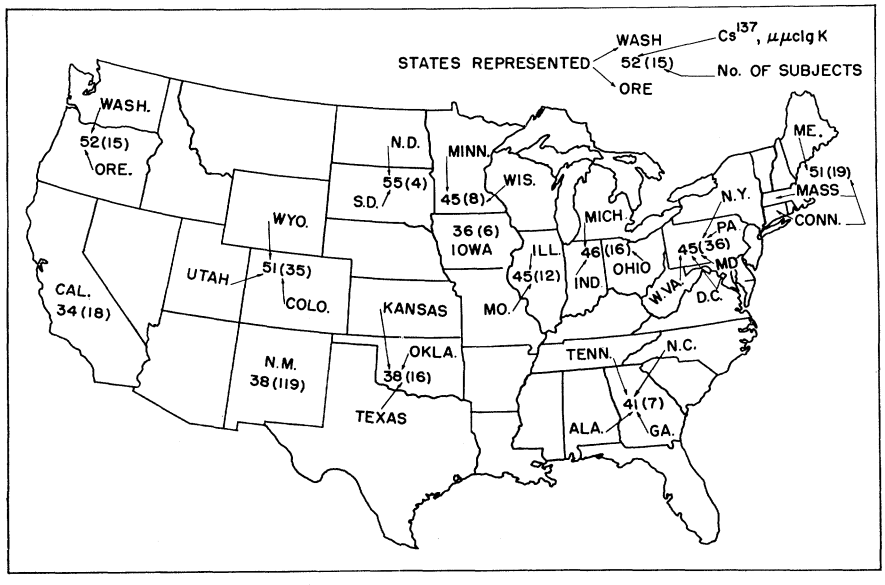

Fig. 5. Map showing cesium-137 levels (micromicrocuries per gram of potassium) in people, by geographic location (1957).

strontium and cesium in the fallout process. We will derive the ratio of the average integrated fallout for 1957 to the average for 1956 from Libby (*9*). These data apply to Pittsburgh and are based on tub collection. Because of the 120-day biological half-life of cesium in man (*10*), the fallout averages are taken over the 1-year period beginning 3 months before the calendar year for which cesium data were obtained. We find the 1956 average cumulated fallout to be 11.3 millicuries per square mile and the 1957 average, 19.4 millicuries per square mile, a ratio of 1:1.72.

Similarly, the ratio of the average rates of stratospheric fallout in the two years can be estimated to be 1:1.23. Table 1 compares the observed cesium increase with that calculated on the basis of these alternatives. These results seem to indicate that direct fallout on the leaves of vegetation is the primary mechanism for cesium-137 entry into the biosphere; this is in agreement with the observed limited availability of soil cesium to plants. However, the result cannot be regarded as conclusive, since Langham and Anderson have shown (*11*) that the observed cesium levels in people are in fair agreement with those calculated on the assumption that uptake from soil is the route of entry.

In Fig. 8, the cesium level in people is plotted against the cesium level in milk from the same areas for 1957. The intercept of this graph for no cesium in the milk indicates that about 23 micromicrocuries of cesium per gram of potassium are derived from a source other than milk. Since milk supplies about 38 percent of the dietary potassium (*1*), the cesium/potassium ratio in the other source must be about 25 micromicrocuries per gram, not very different from the average for milk itself. Most of the other major potassium sources are foodstuffs which are widely exchanged over the country (for example, meat, cereal products, citrus fruits), milk being unique in its localized consumption. Therefore, making a primary local correlation with milk is not unreasonable.

The slope of the line in Fig. 8 is 0.7. If we use, again, the estimate that about 38 percent of dietary potassium is from milk products, this slope indicates a discrimination factor, $(\text{cesium/potassium})_{\text{man}}$ to $(\text{cesium/potassium})_{\text{milk}}$, of 1.8. The discrimination factor calculated from biological half-life ratios is 120 days to 40 days (*1*), or about 3. The value deduced by Miller and Marinelli on the basis of the ratio of excretion to body burden is close to 2 (*12*).

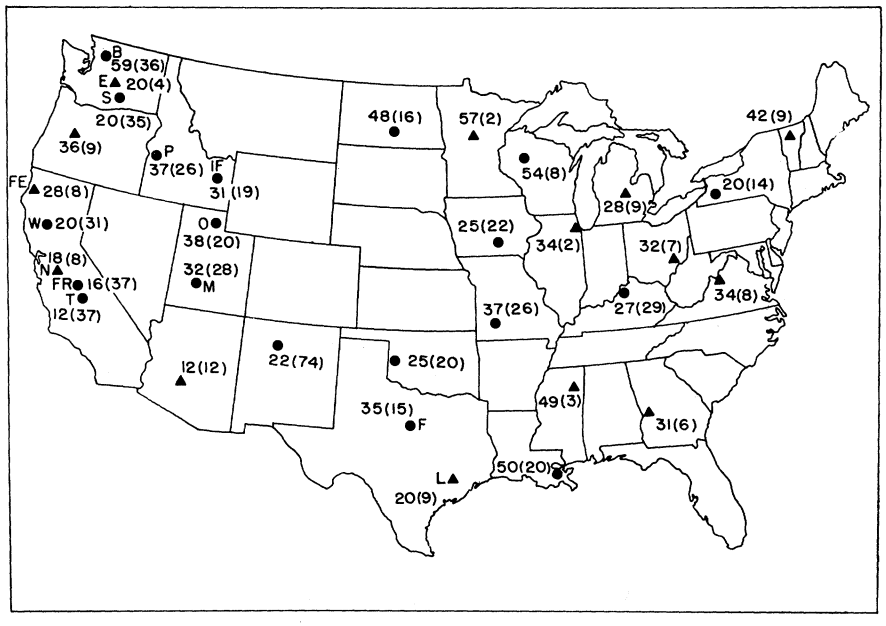

Fig. 6. Map showing levels of cesium-137 (in micromicrocuries per gram of potassium) in milk samples from various parts of the United States (1957).

It has been repeatedly suggested that the intensity of fallout should in some way be related to rainfall, since scavenging by rain seems to be a very efficient process. Such an effect is, in fact, clearly evident in the milk data given in Fig. 6, particularly for the states of Washington and California. We have, therefore, plotted the average cesium-137 content of milk during 1957 against total precipitation (*13*), as shown in Fig. 9. The country divides rather sharply into two regions, each showing a positive correlation but with regression coefficients differing by a factor of 2.6. A similar effect has been reported for strontium-90 in rainfall (*14, 15*). The two regions, as defined by the cesium data, are not separated by a parallel of latitude but rather appear to divide along a line running roughly from El Paso, Texas, northeast to Minneapolis, Minnesota, and thence east through the Great Lakes. Such a division may be explained on the basis of a general tropospheric circulation pattern. The region with a low ratio of cesium to precipitation is the area whose precipitation comes from the south or east, while in the other region the prevailing storm-track pattern is from the west or north.

Conclusions

The results of the past year's operations indicate that the measurement of cesium-137 is a very useful tool in the study of the fallout process. The internal consistency of the data suggests that the number of variables involved, while large, is not insuperably so. Given a moderate expansion of the sampling system and a few more years of operation, one can hope to isolate further the seasonal and meteorological parameters. If there

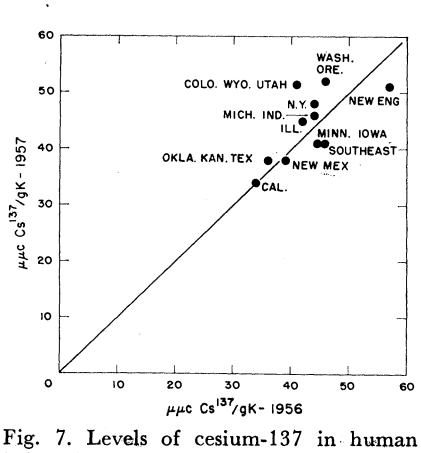

Fig. 7. Levels of cesium-137 in human beings (1956 versus 1957).

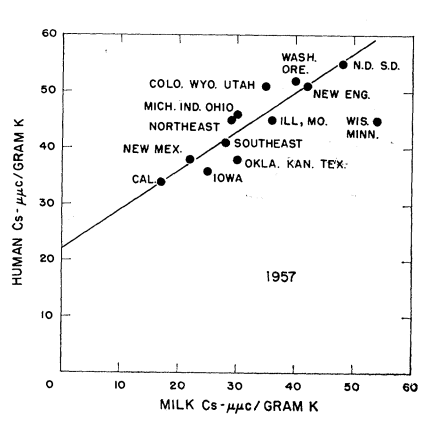

Fig. 8. Levels of cesium-137 in human beings versus levels in milk (1957).

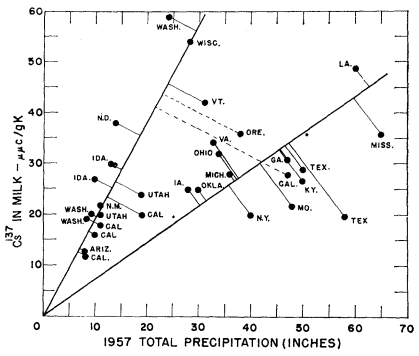

Fig. 9. Cesium in milk versus total precipitation (1957).

should be a cessation of weapon testing, resulting in an uncontaminated troposphere for a few years, one can expect to arrive at definitive data on the rate of stratospheric fallout.

As more conservative calculations are proposed for possible long-term, low-frequency genetic effects, the importance of cesium-137 relative to strontium-90 in fallout is increasing. It is, therefore, more necessary than ever that adequate information on the present levels and their rate of change be available for cesium-137. In addition, the greater facility and economy with which the cesium and potassium determinations can be carried out argue for their greater use in the study of the strontium-90 problem.

Low-level monitoring systems with capacities of tens of thousands of samples per year will also be of the greatest importance in connection with the rapidly expanding power reactor programs. The British experience with contaminated milk after the Windscale incident emphasized the importance of an alert, functioning system for emergency action. However, even in the absence of accidents, the administration of the permissible exposure levels requires detailed radiation studies in the vicinity of all reactors, both before and during operation, and sensitivity levels far enough below the maximum permissible concentrations of activity to give adequate advance warning of possible danger. The psychological value of the reassurance provided the public by continued, detailed monitoring at the natural radiation levels may be as valuable in the long run as the use of the system to provide evidence for or against possible contamination in legal action involving third-party liability. The routine operation of the "Los Alamos human counter" for the past two years is evidence of the practicality of such systems.

Summary

The routine determination of cesium-137 and potassium-40 content of over 2200 samples was accomplished through utilization of one-fifth of the potential capacity of the Los Alamos human counter. Little change in the cesium-137 concentration in people was observed from 1956 to 1957, in spite of the increase in both the rate and the integrated levels of fallout. The correlation of levels in human beings with cesium levels in milk indicates a discrimination factor of 1.8 in this step of the ecological transfer. Precipitation is shown to be an important factor determining the cesium content of milk, but the lack of complete correlation indicates that a more detailed analysis is necessary. Contamination of the troposphere during periods of weapon testing complicates the interpretation, as do seasonal variations.

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3. This work was performed under the auspices of the U.S. Atomic Energy Commission. The data here presented are attributable in large part to the skillful and conscientious efforts of Mrs. B. E. Clinton, who ran many of the samples and performed all the calculations. R. L. Schuch assisted in all phases of the program, and J. L. Shields was responsible for the milk counting. F. C. V. Worman assisted in the analysis of the data, and H. E. Gilbert and W. R. Fisher were responsible for the machine programming. My colleagues and I are grateful to R. P. Choi of the American Dry Milk Institute and to J. W. Ballow for their help in obtaining samples. M. A. Van Dilla determined the gamma spectra of a number of samples as proof of radiochemical purity. We are indebted to T. L. Shipman and W. H. Langham for helpful discussions and generous support.
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