of the generality of these findings. Such studies are now being initiated with finalists in the National Merit Scholarship Program.

Summary

A method for comparing the effectiveness of undergraduate colleges in stimulating their students to seek the Ph.D. is described. The procedure yields separate measures of productivity in the natural sciences and in the arts, humanities, and social sciences, adjusted to control differences in college talent supplies. The results suggest that the productivity measures have substantial validity, and argue for the importance of faculty behaviors in stimulating or inhibiting intellectual achievement.

References and Notes

1. This research was partially supported by the National Science Foundation and the Old Dominion Foundation. I am also indebted to John L. Holland and Laura Kent for their editorial assistance, and to Lindsey Harmon for making available unpublished data on doctorate production in American universities.
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3. R. H. Knapp and H. B. Goodrich, *Origins of American Scientists* (Univ. of Chicago Press, Chicago, 1952). These authors report an analysis for a small sample of 50 colleges in which productivity rates are adjusted for diversities in student quality. Geographic differences and cost of attendance were the only variables which appeared to be significantly related to the adjusted indices (p. 342). However, the major analysis ignores differences in supplies of college talent.
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5. A. E. Traxler, "An appraisal of American colleges on the basis of men graduates listed in *Who's Who in America*" (paper presented at the meeting of the AAAS, Indianapolis, 29 Dec. 1957).
6. The college's first-time, opening enrollment was used as an index of the freshman class: M. C. Johnson and A. J. Fenton, *Opening Enrollment in Higher Educational Institutions, Fall, 1956* and *Fall, 1957*, U.S. Department of Health, Education, and Welfare, Circulars 496 and 518 (Washington, D.C., 1957–58).
7. The product moment correlation between the 1956 and 1957 talent supply indices of 511 colleges is .92. Further, the correlation between mean ACE scores of entering freshmen at 19 Minnesota institutions of higher learning, over the 7-year period 1947–1954, was .80 (data from W. R. Layton, University of Minnesota, personal communication).
8. *The Baccalaureate Origins of Science Doctorates Awarded in the United States, 1936–1950*, Office of Scientific Personnel, National Academy of Sciences–National Research Council, Publ. No. 382 (Washington, D.C., 1955); *Baccalaureate Origins of Doctorates in the Arts, Humanities, and Social Sciences Awarded in the United States, 1936–1950*, Office of Scientific Personnel, National Academy of Sciences–National Research Council, Publ. No. 460 (Washington, D.C., 1956); *Doctorate Production in United States Universities, 1936–1956*, Office of Scientific Personnel, National Academy of Sciences–National Research Council, Publ. No. 585 (Washington, D.C., 1958). The classification of disciplines described in the last-mentioned publication was used in the present study to obtain separate indices, for productivity in the natural sciences and in the arts, humanities, and social sciences; thus anthropology, geography, and psychology are included within the social sciences.
9. *Earned Degrees Conferred by Higher Educational Institutions, 1947–48*, Office of Education, Circ. No. 247 (Washington, D.C., 1949); *Earned Degrees Conferred by Higher Educational Institutions, 1948–49*, Office of Education, Circ. No. 262 (Washington, D.C., 1950).
10. The regression analyses were actually performed on logarithmic transformations of the percentages, since both the rates of producing Ph.D.'s (in the natural sciences and in the arts, humanities, and social sciences) and the rates of enrolling Merit finalists were highly skewed.
11. C. R. Pace and G. C. Stern, *College Characteristics Index, Form 457* (The authors, Syracuse, N.Y., 1957).
12. This is not surprising since the correlations between the two productivity measures are only .09 for the 36 selected institutions and .35 for the entire group of 511 colleges and universities.

Deposition of Strontium-90 through October 1958

The global deposition of strontium-90 is discussed in relation to the absorption of the isotope by man.

Merril Eisenbud

This article is intended to update previous reports (*1, 2*) in which the present and future global deposition of strontium-90 were discussed in relation to the contamination of foods and deposition of this isotope in the skeleton of man.

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Methods of Measurement

The accumulation of fallout in various parts of the world continues to be documented by the methods described earlier. The oldest method is that of the network of gummed films, which was initiated in 1952 and which permits daily observations of the rate and accumulation of fallout at a great many locations in the United States and abroad. In addition, beginning in 1955, soil samples have been collected annually from a number of locations and have been analyzed radiochemically for strontium-90 (*3*). A third method is the collection of deposited or precipitated dust in pots. Such sampling was begun by the United States in early 1954, and the program now includes 41 stations in the United States and elsewhere (*4*).

Although it is the most difficult of the three methods, radiochemical analysis of soil is the best indicator of the possible human hazard in that it is a direct measure of the strontium-90 potentially available for introduction into biological processes. However, for some purposes it is desirable to know not only how much strontium-90 has accumulated in the soil at any given time but what the fallout rate is over a given period of time. The use of pots or gummed film is convenient for determining both.

A serious limitation to the use of gummed films is the fact that the amount of strontium-90 is not determined directly but is computed from a measurement of total beta activity. This computation requires access to classified information concerning the dates and size of nuclear detonations (5). Until June 1957, estimates of cumulative strontium-90 fallout based on gummed-film data were in approximate agreement with estimates obtained from direct radiochemical analyses of samples collected in pots. Figure 1, which has been developed from published data (5, 6), illustrates the comparative data for that time.

Previous articles (5, 7) have called attention to the increasing difficulty of estimating the strontium-90 content of the radioactivity collected by the gummed films. During late 1957 and for the first 10 months of 1958, the tempo of testing was such that the mixtures of tropospheric and stratospheric debris of various ages and in uncertain ratios greatly increased the difficulty of calculating the strontium-90 component from the estimated age of the total beta activity. For this reason, the estimates of strontium-90 from gummed-film measurements have not been continued beyond June 1957. The loss of this source of information has been offset by the fact that the network of monthly pot collections has been expanded greatly since 1957. In addition, an excellent set of soil samples has been collected by the Department of Agriculture at 76 localities in 36 countries.

Pattern of Fallout

The data of the gummed-film network for the years 1955 through 1957 are plotted together with the results of the 1958 soil analyses in Fig. 2. The gummed-film data for the United States and the islands of the trust territories of the western Pacific Ocean were excluded from this figure because the deposition pattern in these areas is affected primarily by local meteorological factors and the location of the testing grounds. For example, the winds in the western part of the United States are such that the strontium-90 deposition at San Francisco, to the northwest of the Nevada proving grounds, was 11 millicuries per square mile in mid-1957 compared with 54 millicuries per square mile at Salt Lake City, located at a comparable distance to the northeast. This difference, which is due entirely to the pattern of the prevailing winds, would mask the less pronounced variations which are attributable to other factors at greater distances from the sites of detonation.

The data for all soil samples collected by the Department of Agriculture (8) are included, but the results from four samples collected in Oahu have been averaged and included as a single value so as to not unduly weigh the average value for the band at 20° to 30° north latitude.

The fallout pattern has varied systematically with latitude during the three years since 1956, but the relatively high North Temperate Zone values were not evident in 1955. The latitudinal variation for the latter three years proves to be in agreement with the work of Stewart *et al.* (9) in the United Kingdom and tends to support the suggestion first made by Stewart and his colleagues that the global pattern of strontium-90 deposition is influenced by the manner in which stratospheric-tropospheric exchange takes place. Citing the model of the exchange mechanism advanced by Brewer (10), Stewart noted that radioactive debris injected into the stratosphere should deposit preferentially in the North Temperate Zone.

It has been noted by others that the North Temperate Zone of maximum deposition coincides with the latitudes in which much of the testing has occurred and that the relatively high deposition values may therefore result from the fallout of tropospheric debris. A strong argument against this possibility is that the 1958 cumulative deposition in the band at 30° to 70° north latitude is about 1.5 megacuries. If all of the tropospheric debris of United States and Soviet origin were deposited in this band, this would account for a maximum of only 25 percent of the observed amount. In view of the fact that some of the debris was known to be deposited outside the 30° to 70° band, one can conclude that stratospheric debris accounts for more than 75 percent of the observed deposition. This is consistent with the estimate of 80 percent I made in 1956 (2).

The areas under the deposition curves may be integrated to yield approximations of the global fallout of strontium-90. The values thus obtained are 0.59, 1.1, 1.9, and 2.3 megacuries, respectively, for each of the four years of ob-

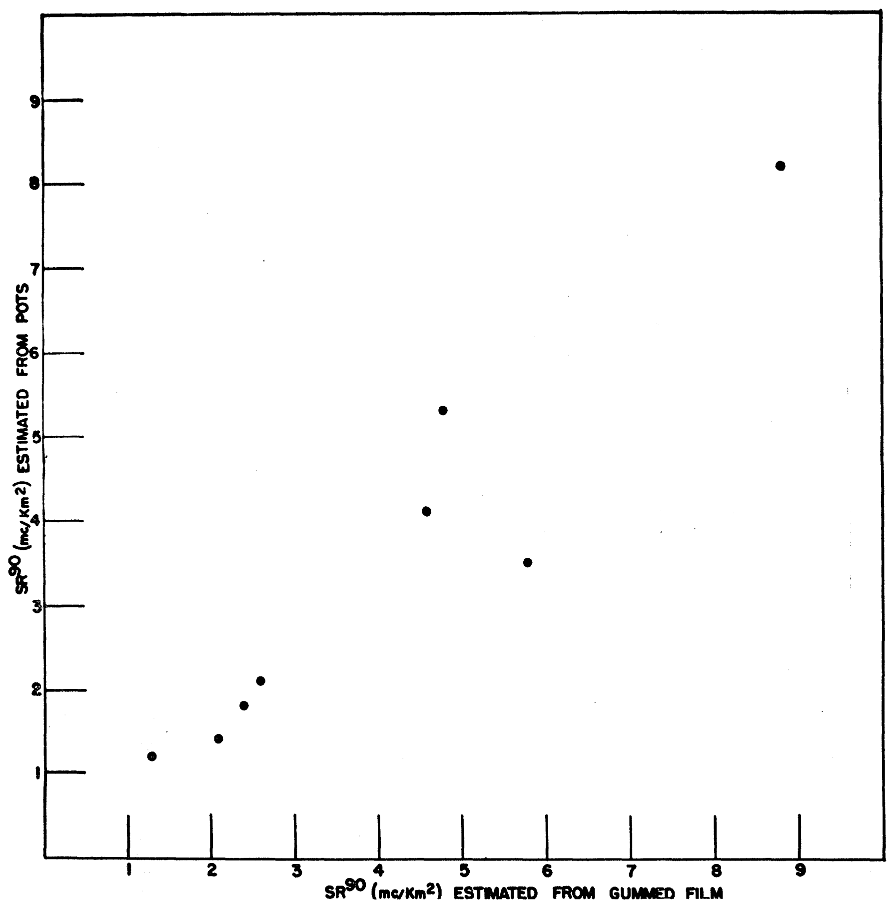

Fig. 1. Comparison of cumulative deposition of strontium-90 at various places as estimated from pot and gummed film samples.

servations. The estimates for 1955 and 1956 have been revised from earlier estimates of 1.0 and 1.5 megacuries (*1, 2*).

The cumulative estimates through 1957 are calculated from measurements of total beta activity (*5*). However, a correction previously used (*7*) on the basis of earlier comparisons of soil analysis with gummed-film estimates has been eliminated in view of the more recent comparative data (*5*).

There has been increased emphasis on stratospheric sampling for strontium-90 both in the United States and abroad. However, data from these studies are as yet preliminary, and one must continue to depend on estimates derived from material balance studies. The starting point in this calculation utilizes classified data of the yields of the individual detonations and estimates of the fraction of the debris that is deposited initially in the vicinity of the detonation. The total amount of strontium-90 distributed in the atmosphere can then be apportioned between the troposphere and stratosphere. This apportionment depends on the energy released in the detonation, the height of burst, and meteorological factors.

Table 1. Concentration of strontium-90 in cow's milk during the last three months of 1958.

Place	Laboratory*	Type of milk	Date sampling was begun	Concentration (μμc/g of Ca)
New York, N.Y.	HASL	Liquid	June 1954	9.8
New York, N.Y.	USPHS	Liquid	May 1957	8.7
Perry, N.Y.	HASL	Dry	April 1954	8.2
Mandan, N.D.	HASL	Dry	April 1955	20
Sacramento, Calif.	USPHS	Liquid	April 1957	4.2
Salt Lake City, Utah	USPHS	Liquid	April 1957	4.8
St. Louis, Mo.	USPHS	Liquid	April 1957	16
Cincinnati, Ohio	USPHS	Liquid	March 1957	10
Atlanta, Ga.	USPHS	Liquid	June 1958	8.8
Austin, Tex.	USPHS	Liquid	June 1958	3.8
Chicago, Ill.	USPHS	Liquid	July 1958	7.4

* HASL, U.S. Atomic Energy Commission, Health and Safety Laboratory, New York; USPHS, U.S. Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

I originally estimated the stratospheric inventory in September 1955 to be 3.0 megacuries (*1*). It now appears that a value of 2.0 megacuries would have been more reasonable. The inventory was estimated to be 1.8 megacuries in June 1956 (*2*) and again in June 1957, indicating that the stratospheric burden remained essentially unchanged during that period. As Libby has previously noted (*11*), the debris injected into the stratosphere apparently compensated for the deposition that took place during those years.

Although global data on the soil content of strontium-90 do not exist beyond the period of collections in early 1958, it is of interest to extrapolate the observed depositions to 1 November 1958, when the suspension of weapons tests took effect. One observes that the increase in global deposition between June 1957 and April 1958 was 0.4 megacuries, or 0.04 megacuries per month. Assuming that this rate continued until the end of October 1958, one may estimate the global deposition to have been 2.6 megacuries of strontium-90 at that time.

Future Deposition

In order to estimate the maximum future deposition from strontium-90, it is assumed that the debris now stored in the stratosphere will be deposited on the earth in approximately the same pattern as that observed in the spring of 1958. It is estimated that 6.4 megacuries of strontium-90 were injected into the stratosphere by all detonations up to 31 October 1958. Of the 2.6 megacuries deposited globally, 20 percent is assumed to be of tropospheric origin. We have thus accounted for 2.1 of the original 6.4 megacuries leaving an estimated stratospheric reservoir of 4.3 megacuries.

The ultimate global deposition may thus be estimated to be the 6.4 megacuries originally injected to the stratosphere plus 0.5 megacuries of tropo-

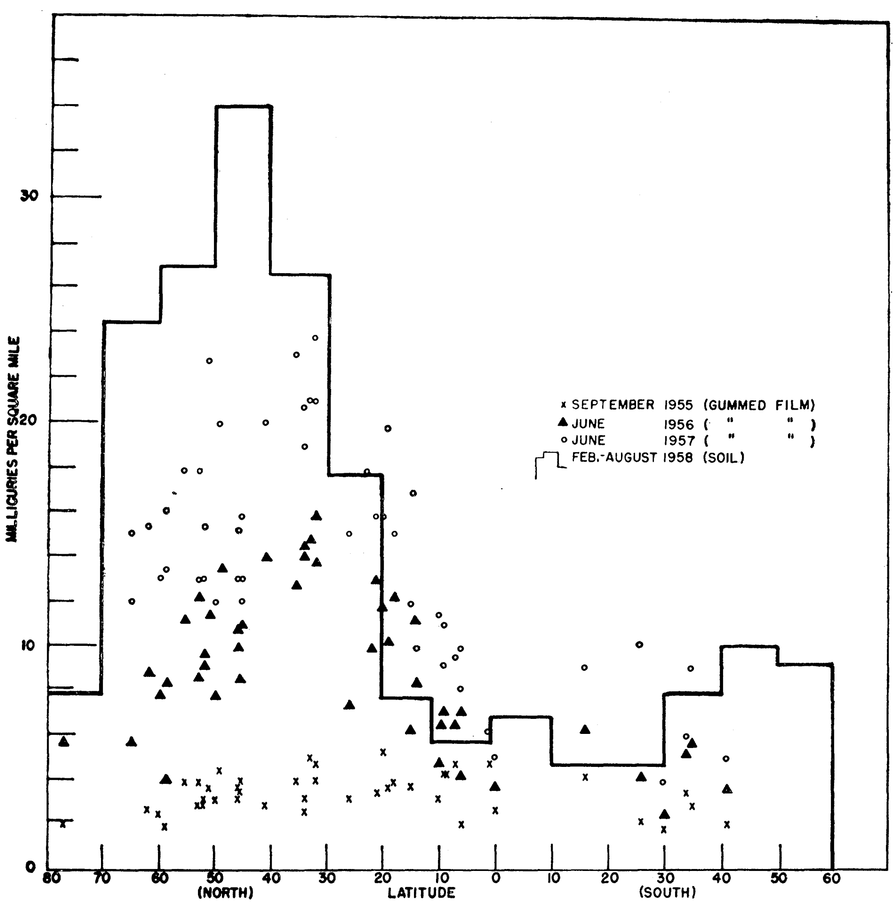

Fig. 2. Estimates of cumulative strontium-90 deposition as a function of latitude for 1955–1959.

spheric origin. This totals 6.9 megacuries from which one must subtract the 25 percent which will have decayed in the next 10 years, by which time over 90 percent of the debris will have been deposited. This is based on the estimate that approximately 50 percent of the stratospheric debris is eliminated every 3 years (*12*). Thus, the deposit on earth will reach approximately 5 megacuries, roughly twice the levels observed in 1958.

Absorption by Man

In the United States and other western countries at least half of the calcium deposited in the skeletons of human beings through adolescence originates from dairy products. Milk has therefore been used as one basis (*1*) for estimating the concentration of strontium-90 which may be expected in human skeletons that reach equilibrium with an environment contaminated with strontium-90.

The Atomic Energy Commission and the U.S. Public Health Service have been analyzing milk from a number of areas in this country and abroad for various periods of time since 1954 (*3, 13*). The concentration of strontium-90 during the last quarter of 1958 is given in Table 1, which also indicates when sampling at each location first began. It is shown that in recent months the concentration of strontium-90 in milk has varied from 4.2 to 20 micromicrocuries per gram of calcium at the locations sampled.

Estimates of the future exposure of human beings to strontium-90 may be based on the assumption that over a period of several months the average concentration of strontium-90 in milk is directly proportional to the strontium-90 in the soil in which the cow's forage is grown. Estimates made in this way are apt to be in error on the high side, because one thus ignores absorption due to foliar deposition of strontium-90. Moreover, this assumption implies that the isotope, once deposited in soil, remains fixed in the root zone of the forage from which cows derive their nourishment.

For New York state, for which data are available for the years since 1954, a coarse proportionality between the concentration of strontium-90 in soil and in milk is demonstrated in Fig. 3. The soil values are derived from radiochemical analyses of soils collected annually at Rochester and Binghamton, New York.

Table 2. Summary of estimates of strontium-90 contamination.

Time of estimate	Cumulative global fallout (Mc)	Stratosphere reservoir (Mc)	Sr^{90} content of New York milk* ($\mu\mu c$/g of Ca)	Expected global deposit in 10 yr assuming 90% deposition of stratospheric debris (Mc)	Maximum expected Sr^{90} content ($\mu\mu c$/g of Ca): New York milk, from tests prior to time of estimate	Maximum expected Sr^{90} content ($\mu\mu c$/g of Ca): Human skeleton in equilibrium with New York milk	Reference
Sept. 1955	0.6	1.9	1.9	1.7	5.5	2.8	*1*
June 1956	1.1	1.8	3.3	2.0	6.0	3.0	*2*
June 1957	1.9	1.8	3.9	2.6	5.3	2.7	This report
Oct. 1958	2.6	4.3	5.9	4.9	11.0	5.5	This report

* Mean of monthly values for calendar year.

Should the trend shown in Fig. 3 continue, the strontium-90 content of milk can be expected to increase when the strontium-90 now stored in the stratosphere is deposited on the earth. From the previous estimate of the stratospheric inventory in late 1958, it follows that if the geographic pattern of future deposition is similar to the pattern of the past, the strontium-90 concentration in both the soil and milk of New York may be expected to double in the years to come.

The milk from New York state contained an average of 5.9 micromicrocuries of strontium-90 per gram of calcium during 1958. It can be anticipated that the level of strontium-90 in the milk in this area may eventually rise to 11 micromicrocuries per gram of calcium from tests conducted up to November 1958. Values of about three times this level would define the upper limit for other areas in the United States.

As was noted previously, the proportionality discussed above will not apply if strontium-90 is leached from the root zone over a period of years. That such leaching does occur is suggested by soil analyses which have shown that during

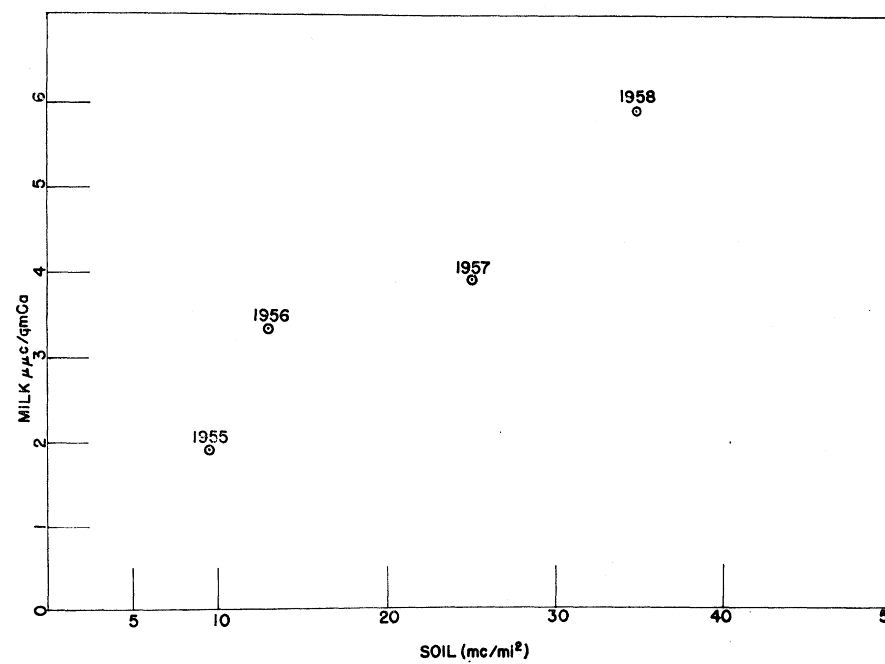

Fig. 3. Mean concentration of strontium-90 in milk from western New York plotted against the mean soil content of stontium-90 at Rochester and Binghamton.

the past three years increasing proportions of strontium-90 have been found in the lower levels (*3*). Estimates of future contamination of foods based on the assumption that strontium-90 is retained in the upper few inches of soil may, over a period of decades, yield estimates which will possibly err on the side of safety.

If, however, we assume that the strontium-90 will remain fixed in the root zones of forage, the only mechanism for diminishing the strontium-90 content of milk will be radioactive decay. Children who are born at the point of maximum soil deposition and who derive their calcium from dairy products, will, for all practical purposes, form a skeleton which is in equilibrium with the strontium-90 contamination of the environment from which their food is derived. Comar (*14*) has shown that skeletons formed from milk diets contain about 0.5 times the strontium-calcium ratio of the original milk. With this discrimination against strontium, human skeletons formed from dairy products in the northeastern United States could reach a maximum strontium-90 concentration of 5.5 micromicrocuries per gram of calcium.

Actual measurements of strontium-90 in human bone have been undertaken by Kulp (*15*) during the past several years. In 1957–58 bones of children in the 1- to 2-year age group contain 1.8 micromicrocuries of strontium-90 per gram of calcium. Kulp's work demonstrated that the values observed in human beings are consistent with the levels of strontium-90 currently found in food.

This is the fourth consecutive year in which it has been possible to make estimates of the maximum foreseeable skeletal contamination for dairy diets in the New York area. The data for these four years are summarized in Table 2. It may be seen from these data that the forecast values have increased markedly during the past year, due in a large measure to the heavy test schedule of the U.S.S.R.

The estimates of future strontium-90 contamination of milk and bone are believed to be conservative estimates of the upper limits of maximum sustained contamination in the New York area. In view of the fact that this mode of computation ignores foliar deposition, and because there is no provision for possible removal of strontium-90 from the soil by natural means other than decay, it is expected that the observed values will in fact be lower than those forecast. On the other hand, during, and for some months following, actual testing, excursions above the forecast levels may be expected in view of the fact that some measure of foliar deposition of strontium-90 is known to occur during such periods.

The United Nations Scientific Committee on the Effects of Atomic Radiation calculated (*16*) that 1 micromicrocurie of strontium-90 per gram of calcium is equivalent to a dose of 1 millirems per year to the bone marrow. An individual having 5.5 micromicrocuries of strontium-90 per gram of calcium in his skeleton will therefore receive a dose of 5.5 millirems per year in addition to the dose from natural radiation of cosmic and terrestrial origin. According to the United Nations Scientific Committee, skeletal irradiation from natural sources is 125 millirems per year. The 5.5 micromicrocuries of strontium-90 per gram of calcium will therefore increase the natural dose to the bone marrow by about 5 percent.

Summary

It is estimated that the global deposition of strontium-90 increased from 1.9 to 2.6 megacuries during the period from June 1957 to October 1958. During this time the stratospheric reservoir of strontium-90 increased from 1.4 to 4.3 megacuries. Approximately 90 percent of the deposition of debris now stored in the stratosphere will have occurred by 1970.

In 1958, the strontium-90 content of powdered milk in the New York area averaged 5.9 micromicrocuries per gram of calcium in comparison with 3.9 micromicrocuries per gram of calcium for the previous year. For this region of the country, the strontium-90 content of milk appears to be increasing in proportion to the strontium-90 content of the soils from which the cows derive their forage.

The upper limit of foreseeable contamination in milk can be estimated by assuming that this proportionality will continue until all of the strontium-90 has been deposited from the upper atmosphere. This procedure should yield estimates which tend to err on the side of safety. In this manner, it is estimated that the maximum foreseeable sustained level of milk contamination in the New York area is 11 micromicrocuries per gram of calcium. A child deriving its calcium from dairy sources may be expected to develop a skeleton having 5.5 micromicrocuries per gram of calcium. This estimate is double that made in June 1957 and reflects the increased stratospheric inventory due to U.S.S.R. detonations in 1958.

The radiological dose to the skeleton from natural sources such as cosmic rays, radium, potassium, and so forth, is approximately 125 millirems per year. A skeletal burden of 5.5 micromicrocuries of strontium-90 per gram of calcium will deliver a dose of approximately 5.5 millirems per year to the bone marrow. The maximum foreseeable dose from strontium-90 in the New York area is thereby estimated to be about 5 percent of the dose due to natural radioactivity.

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