Letters

Estimates of Radiation Dose from Strontium-90 Due to Fallout

A recent article by Merril Eisenbud, "Deposition of strontium-90 through October 1958," concludes, from consideration of the radiation delivered to bone marrow by the Sr^{90} absorbed by the bone from fallout debris, that "the maximum foreseeable dose [of radiation] from strontium-90 in the New York area is thereby estimated to be about 5 percent of the dose due to natural radioactivity" (*1*).

This conclusion appears to be inaccurate. In what follows it is shown that, instead, on proper calculation, Eisenbud's data lead to the conclusion that Sr^{90}-induced radiation to the bone marrow is, on the average, 15 to 60 percent of the natural background radiation. Some localized areas of bone marrow will receive considerably more intense radiation. Such calculations show also that the bone itself will receive, from Sr^{90}, radiation amounting to from 10 to 400 percent of the background radiation.

Eisenbud estimates that when Sr^{90} deposition due to fallout from past tests is at a maximum (in 1965), milk in the New York area will reach the level of 11 $\mu\mu c$ of Sr^{90} per gram of calcium, and that a child using this milk as a source of dietary calcium will develop a skeleton containing about 5.5 $\mu\mu c$ of Sr^{90} per gram of calcium (5.5 strontium units). For the purpose of this discussion this estimate is accepted as a first approximation, although, as shown below, it is probably too low. Eisenbud calculates, from the skeletal Sr^{90} level given above, the resultant radiation dose to the bone marrow. This dose is then compared with a value representing the dose from natural radiation, and it is concluded that the fallout radiation amounts to 5 percent of background radiation. Eisenbud's considerations of this matter are contained in the following paragraph from his article: "The United Nations Scientific Committee on the Effects of Atomic Radiation calculated . . . [(*2*)] that 1 micromicrocurie of strontium-90 per gram of calcium is equivalent to a dose of 1 millirem 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."

According to the United Nations report (*2*, p. 9, Table 1, and p. 58, Table 25), the natural radiation to the *bones* is 125 to 130 mrem/yr, while the natural radiation to the *bone marrow* is 95 mrem/yr. Eisenbud's comparison appears to be between an estimated Sr^{90} radiation to the bone marrow and the natural radiation to the bone.

More properly, Sr^{90} and natural radiation ought to be compared relative to the same tissue, either bone or bone marrow. Such comparisons lead to the following results.

1) With regard to bone, according to the U.N. report (*2*, p. 107, par. 63), 1 $\mu\mu c$ of Sr^{90} per gram of calcium delivers to bone tissue 2.5 mrem/yr. Thus, 5.5 $\mu\mu c$ of Sr^{90} per gram of calcium will result in a bone dose of 13.8 mrem/yr, or about 10 percent of the natural dose (125 to 130 mrem/yr). This estimate refers only to an average value and assumes that the Sr^{90} is evenly spread throughout the skeleton. However, it has been shown by Engström *et al.* (*3*) that microscopic regions of the bone may receive a radiation dose about 40 times the average. Hence, these parts of the skeleton will receive from Sr^{90} a radiation dose amounting to about 400 percent of the radiation from natural sources.

2) With regard to bone marrow, a similar situation exists. This problem is considered in paragraphs 64 and 65 on pages 107 and 108 of the U.N. report (*2*). Paragraph 64 states: "In the following it will be assumed that 1 strontium unit [1 $\mu\mu c$ of Sr^{90} per gram of Ca] will cause a mean bone marrow dose rate of 1 mrem/yr. The true value of the mean marrow dose might however, be as low as 0.5 or as high as 2 mrem/year per strontium unit." The problem is further developed in paragraph 65, which states: "It should be emphasized that bone marrow cells which are almost surrounded by bone will receive doses which may be equal to those in compact bone. Taking into account all causes for non-uniformity, i.e. the non-uniform deposition in the mineralized zones, the variation in bone layer widths and geometrical factors [corners], the bone marrow level is probably five times the figures quoted above."

Eisenbud has chosen to employ, as the parameter relating Sr^{90} concentration to radiation dose, the ratio 1 mrem/yr per strontium unit. However this choice ignores the variability range (0.5 to 2 mrem/yr per strontium unit) given in paragraph 64 of the U.N. report, and the fivefold inhomogeneity factor cited in paragraph 65. If *all* the relevant data in the U.N. report are considered, we reach the conclusion that an average skeletal burden of 5.5 $\mu\mu c$ of Sr^{90} per gram of calcium will deliver to localized regions of the bone marrow between 14 (5.5 strontium units × 0.5 mrem/yr per strontium unit × 5) and 55 (5.5 strontium units × 2 mrem/yr per strontium unit × 5) mrem/yr. When these dose rates are compared with the natural rate of 95 mrem/yr, we find that Sr^{90} will contribute to the bone marrow additional radiation amounting to about 15 to 60 percent of the radiation from natural sources.

The foregoing considerations are based only on the sources of data employed by Eisenbud. If other pertinent information is taken into account the above conclusion becomes modified further. As pointed out with reference to a recent estimate of the expected dietary Sr^{90} levels in St. Louis (*4*), data reported by H. P. Straub of the U.S. Public Health Service to the recent hearings on fallout before the Joint Committee on Atomic Energy show that about one-third of dietary Sr^{90} comes from nonmilk sources. Since these sources, principally cereals and vegetables, have Sr^{90} concentrations considerably higher than those of milk, the total dietary Sr^{90} level with which bone is in equilibrium is higher than is indicated by estimates based on milk alone. Consideration of this factor would increase the foregoing estimates of Sr^{90} radiation to bone and bone marrow by a factor of about 50 percent. In addition, as Caster (*5*) has pointed out, calculations by Engström *et al.* (*3*) indicate that a heterogeneity factor of 40 to 60 (as against the value of 5 suggested in the U.N. report) may be operative in some conditions. In this case the effect of Sr^{90} relative to natural radiation would be increased proportionately.

In sum, Eisenbud's conclusion appears significantly to underestimate the relative effect of radiation from Sr^{90} resulting from fallout due to nuclear explosions. Since Eisenbud's article is part of the testimony before the recent hearings on fallout before the Joint Committee on Atomic Energy, consideration should be given to appropriate means of correcting the record of these hearings.

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References

1. M. Eisenbud. *Science* 130, 76 (1959).
2. *Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, Suppl. No. 17 (A/3838)* (1958).
3. A. Engström, R. Bjornerstedt, C-J. Clemedson, A. Nelson, *Bone and Radiostrontium* (Wiley, New York, 1958).
4. See *Nuclear Information,* May-June 1959 (Greater St. Louis Committee for Nuclear Information, St. Louis, Mo., 1959), pp. 1-2.
5. W. O. Caster, *Minn. Chemist* 21, 8 (1959).

Commoner's principal criticisms of my article are (i) that my dose estimates did not allow for inhomogeneities in Sr^{90} deposition or for the ranges in the published estimates of dose per strontium unit, and (ii) that I underestimated the dose from Sr^{90} by assuming that the isotope is derived by human beings from dairy sources only.

In addition to these two points, which I will discuss further, Commoner calls attention to my reference to 125 mrem/yr as the natural "skeletal" radiation dose. The dose to the *bone marrow* from natural sources was actually assumed to be 95 mrem, the value I used in concluding that 5.5 mrem/yr is "about 5 percent" of the dose from natural sources. The value of 125 mrem/yr to the *bone* was given redundantly in the text. I am indebted to Commoner for calling this to my attention.

The method I used in estimating the dose to bone marrow was adopted directly from the procedures developed by the United Nations Scientific Committee on the Effects of Atomic Radiation. It is significant that this committee relied on bone marrow dose rather than on osteocyte dose in calculating the biological consequences of Sr^{90} deposition. It is true that, as Commoner says, the use of 1 mrem/yr per strontium unit "ignores" the range of estimates given in the United Nations report (0.5 to 2 mrem/yr per strontium unit), but I considered the assumed value to be a satisfactory basis for tissue dose approximation, as indeed did the U.N. Radiation Committee in the calculations for their report. Commoner notes also the fivefold inhomogeneity to which the U.N. report refers, and he states that I should have used this in my computation. Again, the U.N. Committee simply pointed out that this inhomogeneity probably exists, but they did not find it necessary to include this factor in the computations either of dose or of the biological consequences of Sr^{90} deposition.

The doses we are discussing are very much less than the smallest dose required to produce observable effects in the laboratory. Commoner's concern with the significance of these doses derives from the concept that prudence in estimating the possible consequences of the exposure of large populations to small doses of radiation requires one to assume that there is no threshold, and that the biological consequences of radiation doses, however small, can be estimated by a linear extrapolation of existing experimental data. This concept is not applied to all of the biological effects of radiation and is not accepted by many investigations of Sr^{90} toxicity as being applicable to the carcinogenic effects of this isotope.

It is not my purpose to argue for or against this concept but merely to note that it exists and serves as the basis of the concern which Commoner and others have experienced over the possible consequences of small doses of Sr^{90}. This being so, I am puzzled that Commoner continues to emphasize the importance of inhomogeneities in deposition of Sr^{90} at dose levels of the order of a few millirems per year. It is true that the portion of the bone marrow in which more than the average amount of the isotope is deposited receives more than average irradiation. The nonthreshold, proportional theory would suggest that the probability of carcinogenesis would thus be increased correspondingly within that portion of the marrow. However, it is likewise true that the remaining portion of the tissue will have less than the average dose and, for this remaining portion, the probability of carcinogenesis will be lessened. According to the proportional theory, the probability of a carcinogenic response in a given volume of tissue should be a function of the total energy absorbed within the tissue.

Commoner's criticism of my use of milk as the basis for computing potential risk does have merit. Foods other than dairy products have been shown recently to be contributing increasingly large proportions of Sr^{90} to the diet, and this factor should be considered in future computations. Whether or not omission of this factor does in fact imply that I underestimated the dose by a factor of 0.5, as suggested by Commoner, I cannot say at this time.

It is my opinion that "about 5 percent" is a reasonable estimate of the maximum increase in bone marrow dose to be expected. "About 5 percent" could mean that the actual levels would be as much as 10 percent, but in my opinion, it is more likely that the true values will prove to be somewhat lower than 5 percent. This is because the method I used to compute future doses does not allow for the effect of foliar deposition or the possibility that Sr^{90} in soil will become less available to plants over a period of many years.

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Teaching and Research

The point that Jesse D. Rising raises [*Science* **130**, 66 (10 July 1959)]—that "many potentially excellent teachers may be doing less than their best teaching in an effort to satisfy the university administration by doing research"—was answered forcefully by an experienced teacher in these words:

"In the life of a university department the interests of research and of teaching are competitors. . . . The activities themselves are in necessary conflict in any department which thus seeks to serve two masters. The activities compete for room space, for the working time of staff members, including mechanicians and secretaries, for funds, and for the control of faculty appointments. . . .

"In my experience the demands of teaching and of research have been in continual conflict for nearly forty years, and I cannot remember that either function ever helped the other. Many a demonstration would have been better prepared and many a student better served if the urgency of some situation in the research laboratory (and the fascination of it) had not pulled in that direction. On the other hand, the continuous concentration that a research dilemma can demand was often broken up by the class bell. I would have done better at either one of these activities if I had kept out of the other, and I suspect that there are hundreds of scientific men who could give the same testimony. This is not a situation that we can take any satisfaction in but is just one of the facts of academic life. . . .

"It does seem that it is high time to