Armed Forces and has been assigned number 657 in the series of papers approved for publication. The views or conclusions contained in this report are those of the authors. They are not to be construed as necessarily reflecting the views or endorsement of the Department of Defense. The technical assistance of Marcia Davidson, Miles Connor, and Leon Lind is gratefully acknowledged.

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Radiostrontium Fallout from Continuing Nuclear Tests

In spite of widespread comment on the problem of the fallout of radiostrontium from testing thermonuclear weapons, confusion persists in the public mind and perhaps among many of the readers of *Science* as well regarding the relationship of Sr^{90} accumulation on the ground to such factors as assumed mean storage time in the stratosphere and the rate of testing of thermonuclear weapons. Libby's recently published report on the AEC's studies of the Sr^{90} problem (*1*) was not addressed to the effects of continuing weapons tests. Yet his conclusions have recently been quoted in the press as if they were valid if tests continue provided only that test rates remain unchanged.

Libby's analysis considered essentially the question whether nuclear weapons tests to date may have committed us already to an intolerable accumulation of Sr^{90}. Happily they have not. Speaking to that point, the meteorologists on the National Academy of Sciences study of the biological effects of atomic radiation stated, "At present, the amount of Sr^{90} in the stratosphere from nuclear weapon tests is far too small to approach maximum permissible concentration even if it all were to be deposited now. However, if the testing programs of the several countries producing thermonuclear weapons were to intensify, stratospheric storage time may become a critical item in terms of hazard to mankind. For this reason, a continuing program to investigate this phenomenon is needed, including actual measurements of the radioactivity in the stratosphere and improved and more representative methods of observing fallout" (*2*, p. 60).

The consequences of continued tests can be discussed in terms of a simple mathematical model which is generally accepted by Libby and others in this country as well as in England (*3*). Assume that Sr^{90} is introduced at a constant rate n into the stratosphere, where it is immediately mixed uniformly over the entire globe. According to British data, mixing is evidently reasonably rapid (*3*, p. 11). Assume further that fallout occurs at a rate $R = kQ$, where Q is the instantaneous stratospheric storage and k is the reciprocal of the mean stratospheric storage time.

Accumulated radiostrontium on the ground, M, can then be shown to be

$$M = \frac{n}{\lambda}\left[\frac{k}{k+\lambda} + \frac{\lambda}{k+\lambda}\, e^{-(k+\lambda)t} - e^{-\lambda t}\right] \quad (1)$$

where λ is the radioactive decay constant of radiostrontium. If the constants are expressed in years and the rate of testing is expressed in terms of millicuries of Sr^{90} per square mile of the earth's surface introduced per year into the stratosphere, M is given in terms of millicuries of Sr^{90} per square mile at t years. When $t = \infty$

$$M_{\max.} = \frac{nk}{\lambda(k+\lambda)} \quad (2)$$

and the maximum accumulation of fallout is seen to be proportional to the test rate.

Using Libby's best estimate for the mean stratospheric storage time of 10 years and a conservative estimate of the test rate corresponding to the introduction of 2.5 mc/mi² yr, per year as a reasonable value for n, the maximum accumulation of radiostrontium would be about 80 mc/mi². Libby, *considering only the Sr^{90} produced up to 1955,* predicted maximum fallout of less than one-tenth this amount. The two figures should not be confused.

It is not yet known what fraction of the total radiostrontium produced from a thermonuclear weapon reaches the stratosphere and becomes involved in the fallout process discussed here. For this reason, we do not know how to interpret available data on test rates and accumulation of Sr^{90}—for example, whether little has reached the stratosphere and has subsequently fallen out again relatively quickly or whether much has entered the stratosphere but has been held back by a long storage time. It cannot be said with much confidence, therefore, what rate of weapons testing would result in a given accumulation of Sr^{90}.

Assuming a 10-year storage time and a continuing test rate about twice that mentioned in a previous paragraph (corresponding to estimates made by Stewart, Crooks, and Fisher in the United Kingdom), the Sr^{90} accumulated on the ground after about 35 years would be 80 mc/mi². This would correspond to about 0.14 MPC (maximum permissible concentration) unit in the soil. According to Libby (*4*), Sr^{90} levels in soils are converted to levels in bones of young children at about 70 percent efficiency. This reduces the figure for levels in young children after 35 years of continuous tests to about one-tenth the permissible levels as established for *occupational* exposures. The concentration would not fall much below 0.07 MPC unit even if storage time were found to be 20 years instead of 10. Recently committees of the National Academy of Sciences (*2*, p. 39) and the British Medical Research Council (*5*, par. 281) have expressed their belief that only 0.1 MPC unit or less should be permitted for the population at large. In fact, the British report stated (*5*, par. 360) "So far as radioactive fallout may affect the individual, we believe that immediate consideration would be required if the concentration of radioactive strontium in bone showed signs of rising greatly beyond that corresponding to one-hundredth of the maximum permissible occupational concentration." The rate of introduction of Sr^{90} into the stratosphere assumed here is close to that estimated by Libby for the past three years. On the assumptions made here, therefore, a long-term test program could conceivably reach or exceed the levels of Sr^{90} considered safe for the whole population.

There is little reason to hope that what may be learned about storage time, k, will change this situation much. We must hope that new information may allow us to increase the maximum permissible concentration of radiostrontium in the bodies of the people of the world, that means may be found to decrease the input of Sr^{90} to the stratosphere from tests, or, preferably, that a new attitude among the people of the world will permit us to lower the test rate, n.

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References and Notes

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4. *Note added in proof*: In an address before the AAAS, on 12 Oct. 1956, Libby presented data indicating that the efficiency is more likely between 10 and 30 percent. He also estimated that in the past 2 years Sr^{90} was introduced into the stratosphere at an average rate of 6 mc/mi² yr, or more than twice the rate assumed in the calculations of this paper. Libby's address will be published in *Proceedings of the National Academy of Sciences.*
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