Radioactive Fallout in the United States

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THIS report summarizes the data accumulated up to the present time by the fallout monitoring network of the U.S. Atomic Energy Commission (*1*). Having reviewed the information obtained through early 1952 in a previous article (*2*), we now add the data obtained in more recent atomic tests, including the Pacific exercises in the fall of 1952 (Operation Ivy), the Nevada tests early in 1953 (Operation Upshort-Knothole), and the Pacific tests in the spring of 1954 (Operation Castle).

The data are representative of the entire area of the United States except that within 200 mi of the Nevada Test Site. This region is not covered by the monitoring system described here, but the radioactive fallout within this area has been reported in the semiannual reports from the AEC to the Congress (*3, 4*).

Description of monitoring system. When tests are under way in Nevada, the monitoring network consists of 89 sampling stations (*5*), but at other times the number is reduced to 41, a reasonable distribution of sampling sites for the more diffuse radioactive debris that may originate from detonations beyond the continental limits.

Table 1 lists the stations that are operating during the Nevada tests this spring. These stations, with the exception of Cleveland, Ohio, Cape Hatteras, N. C., and Concord, N. H., were also in operation during the 1953 spring tests in Nevada (Upshot-Knothole); those marked with an asterisk were in operation during the Pacific tests conducted in the spring of 1954 (Castle).

The 1-ft^2 gummed surface previously described (*2*) continues to be used to collect samples. The adhesive is supported on an acetate film mounted horizontally on a frame about 3 ft above the ground. The coating retains its adhesive properties when it is wet, and dust particles that are entrapped in raindrops are collected. The gummed films are changed each day and are mailed to the AEC Health and Safety Laboratory in New York, where their radioactivity is assayed.

The samples are prepared for analysis by ashing at 550° to 600°C. This results in the loss of some volatile isotopes, such as those of iodine and ruthenium, but these comprise less than 10 percent of the total activity. This defect in procedure is justified by the simplicity of the operation.

The small amount of residual ash is transferred to plastic planchets that are sealed between two layers of vinyl tape for automatic beta counting (*6*). These counters have a background of 7 to 10 counts/min and efficiencies of the order of 10 percent. Samples are counted for 20 min, or for 640 counts if this occurs before 20 min have elapsed. Blanks and standards are sealed into every tape. The counts are extrapolated using the $t^{-1.2}$ law to express decay.

This method of monitoring fallout is exceedingly sensitive. We have observed that a general rise in the gamma background of 10^{-4} r/hr is associated with fallout of approximately 10^6 disintegrations/min ft^2. The counting procedures in routine use in this laboratory permit detection of a daily fallout of as little as 10 disintegrations/min ft^2. It is thus possible for us to detect radioactivity that produces a general elevation of background of about 10^{-9} r/hr. The normal gamma background count, which is caused by cosmic rays, radiopotassium, radium, and other natural sources of radioactivity, is quite variable in the range of 5×10^{-6} to 5×10^{-5} r/hr. This method thus makes it possible to estimate minute amounts of radioactivity that are insufficient by far to affect measurably the general gamma radiation background of an area.

It is clear that no one sampling procedure provides the ideal method for estimating the deposition of radioactive dust under all conditions. The deposit on any given area will depend somewhat on the character of the surface presented. For example, when there is no rainfall, dry fallout may drift somewhat with other windblown dusts. In this situation the gummed filter technique may yield a high estimate of the average fallout, because it will tend to collect dust that is being redistributed laterally.

We have compared the collection characteristics of the gummed film (G) and a high-walled pot (P). During a 49-wk period we found that the regression of P on G was 1.17 ± 0.19. This is a highly significant relationship that does not differ significantly from 1.

Methods of collection utilizing pots or pans for collection of total rainfall are disadvantageous in practice because of the need to transfer and handle the wet samples preparatory to shipping to a central radiochemical facility. The gummed-film method is uniquely simple—at the end of the sampling period the film is folded and placed with a data card in an envelope for mailing to the Health and Safety Laboratory, where it is processed in the manner described.

The routine operation of this network has been greatly facilitated by the cooperation of the U.S. Weather Bureau, at the stations of which our collectors are placed. Duplicate samples at all stations provide insurance against loss of samples and also give the advantage of replication.

We have discontinued the routine monitoring of air-borne (suspended) dust at all locations. We have previously reported (*2*) that the highest daily mean air-borne dust concentration recorded during the Nevada tests in the spring of 1952 was 23×10^{-3} $\mu\mu$c/cm^3 (equivalent to 53,000 disintegrations/min

m^3) at Elko, Nev., on 1 June. The estimated cumulative dose to the lungs of persons who breathed this concentration is 20 millirads (*7*), somewhat less than the dose from a chest x-ray. We now have the experience gained during a more recent Nevada series of tests, those conducted in the spring of 1953. We collected samples of air extensively during that series, but none was as high as this previously recorded maximum level.

Accumulation of radioactive fallout. Figure 1 gives our estimates in millicuries per square mile of the total fission products deposited throughout the country since early 1951. These estimates are based on approximately 250,000 samples collected since 1951. The accumulation varies from 21 mc/mi^2 in Arizona to 120 in New Mexico. The mean of the reported value is 61 mc/mi^2. The spread is rather narrow in view of the many factors that affect the amount of fallout in any given place. Nevada is not included because gradations in the fallout patterns make it impractical to assign a single value for the state.

Table 1. Network of collection stations (Feb. 1955). The stations in operation during Operation Castle, the Pacific tests conducted in the spring of 1954, are indicated by an asterisk.

Mobile, Ala.	Kalispell, Mont.
Montgomery, Ala.	*Scottsbluff, Neb.
Flagstaff, Ariz.	Elko, Nev.
Phoenix, Ariz.	Ely, Nev.
*Tucson, Ariz.	*Las Vegas, Nev.
Yuma, Ariz.	Reno, Nev.
Fort Smith, Ark.	Winnimucca, Nev.
Eureka, Calif.	*Concord, N.H.
Fresno, Calif.	*Albuquerque, N.M.
*Los Angeles, Calif.	Roswell, N.M.
Sacramento, Calif.	Albany, N.Y.
San Diego, Calif.	*Binghamton, N.Y.
*San Francisco, Calif.	*Buffalo, N.Y.
Colorado Springs, Colo.	*New York, N.Y. (La Guardia)
Denver, Colo.	*Rochester, N.Y.
*Grand Junction, Colo.	Syracuse, N.Y.
Pueblo, Colo.	*Cape Hatteras, N.C.
*New Haven, Conn.	Fargo, N.D.
*Washington, D.C. (Silver Hill, Md.)	Williston, N.D.
*Jacksonville, Fla.	*Cleveland, Ohio
*Miami, Fla.	*Medford, Ore.
*Atlanta, Ga.	Portland, Ore.
*Boise, Idaho	*Philadelphia, Pa.
Pocatello, Idaho	*Pittsburgh, Pa.
*Chicago, Ill.	Providence, R.I.
*Des Moines, Iowa	Charleston, S.C.
Concordia, Kan.	Huron, S.D.
Goodland, Kan.	*Rapid City, S.D.
*Louisville, Ky.	*Knoxville, Tenn.
*Wichita, Kan	*Memphis, Tenn.
*Louisville, Ky.	Abilene, Tex.
*New Orleans, La.	Amarillo, Tex.
Caribou, Me.	*Corpus Christi, Tex.
Baltimore, Md.	*Dallas, Tex.
*Boston, Mass.	Del Rio, Tex.
Alpena, Mich.	Port Arthur, Tex.
*Detroit, Mich.	Milford, Utah
Marquette, Mich.	*Salt Lake City, Utah
Grand Rapids, Mich.	Lynchburg, Va.
*Minneapolis, Minn.	*Seattle, Wash.
Jackson, Miss.	Spokane, Wash.
*Kansas City, Mo.	Green Bay, Wis.
*St. Louis, Mo.	Milwaukee, Wis.
*Billings, Mont.	Casper, Wyo.
Helena, Mont.	Cheyenne, Wyo.

The manner in which each of the test series has contributed to the total fallout now estimated to be present in the northeastern United States is illustrated in Fig. 2, which continues the type of graphical presentation first used in our earlier report. In order to facilitate the presentation of these data, we have made the simplifying assumption that the debris from each of the detonations of a series of tests originated from a single burst occurring at the midpoint of the series. The total artificial radioactivity continues to be of a low order when it is compared with the radioactivity normally present in the earth's crust. The naturally occurring isotope Ra^{226} is present in amounts that vary between 100 and 1000 mc/mi^2, considering only the upper few inches of the earth's crust.

Of the various long-lived constituents present in this radioactive debris, Sr^{90} is of most interest. This is because of its relatively long half-life (25 yr) and the fact that its chemical similarity to calcium makes it possible that strontium can enter into biological systems along with calcium and ultimately be deposited in human bone. As is well known, this is also true of radium.

The estimated accumulation of strontium in the soil in northeastern United States is also shown in Fig. 2. The contribution from Sr^{89} is not shown because of its relatively short half-life (55 days). The ratio of Sr^{89} to Sr^{90} in the accumulated debris from all detonations is estimated to have been about 1.0 on 1 Jan. 1955.

By 1 Sept. 1954 the estimate of accumulated Sr^{90} was 1 mc/mi^2. This estimate is based on the assumption that Sr^{90} is present in the debris in an amount that can be predicted from the data of Hunter and Ballou (*8*). The proportion of Sr^{90} of the debris may vary somewhat from theory, and more or less Sr^{90} may be present. This is consistent with the manner in which Sr^{90} is formed and the general dynamics of the fireball as we presently understand it. The Sr^{90} is derived from a radioactive parent Kr^{90}, which is an inert gas having a half-life of 25 sec. Thus, much of the Sr^{90} that is ultimately present in the debris is formed when the fireball is relatively old and has cooled considerably. This can result in the presence of a disproportionate fraction of Sr^{90} in a given particle of debris. A tentative assumption, supported by incomplete studies, is that the debris which falls out in the immediate vicinity of a detonation is depleted in Sr^{90}. Conversely, the debris that falls out at great distances is likely to be enriched in this nuclide. Re-

cent unpublished analyses from our laboratory suggest that the use of the Hunter and Ballou curves to estimate the radiostrontium content of our samples may yield values that are about 30 percent of the true value. The same reasoning applies to Sr^{89}, which is also derived from a krypton isotope.

However, an upward adjustment, by a factor of 3, of our estimates of the Sr^{90} contribution to the earth's crust does not alter the conclusion that the fallout of long-lived radioactive constituents of the debris has been minute compared with the radioactivity that is normally present in the earth's crust. Bugher (*9*) recently estimated that the amount of strontium present would have to be increased by the order of 1 million times before the biological effects from this cause could be recognized.

In a few places relatively heavy fallout caused by a combination of meteorological coincidences resulted in elevations of the radiation background that were readily detectable with conventional radiation detection equipment. In each case the fallout was associated with precipitation coinciding with the transport of radioactive dust into the rain-forming levels of the atmosphere. The bulk of this radioactivity is eliminated by decay in the matter of hours or a few days after the fallout. At no place except in the immediate vicinity of the test site in Nevada is there a sustained elevation of the background sufficient to be demonstrable by direct measurement of the gamma background in the area. For example, the deposition of mixed fission products in New Mexico is estimated to have been approximately 120 mc/mi² on 1 Jan. 1955. The gamma radiation from this deposition is of the order of 0.0010 mr/hr; the normal background of the United States varies from 0.005 to 0.05 mr/hr and in any one place may vary by as much as a factor of 5, primarily because of meteorological situations that inhibit the dispersion of the radioactive gas radon and its daughter products. It would be difficult, although possible, to measure the increase in dose rate caused by 100 mc/mi².

An example of relatively heavy fallout was the radioactive rain in Troy, N. Y., of April 1953. This instance was particularly well documented by Clark (*10*). Although Troy is located at a great distance from the Nevada test site, the fallout on that city is to our knowledge the highest that has occurred except, as reported elsewhere (*4*), for some of the communities located within 200 mi of the Nevada test site. Clark reported that the cumulative dose from Troy fallout was about 100 mr. It is apparent from this and previous descriptions of methods by which we document radioactive fallout at distances from the site of a detonation that the widespread dispersion of radioactive debris is readily demonstrable by rather simple techniques.

It is not surprising that at times anomalously high fallout at great distances from a detonation has been readily observed by conventional radiosensitive laboratory equipment. It will be recalled that fallout from

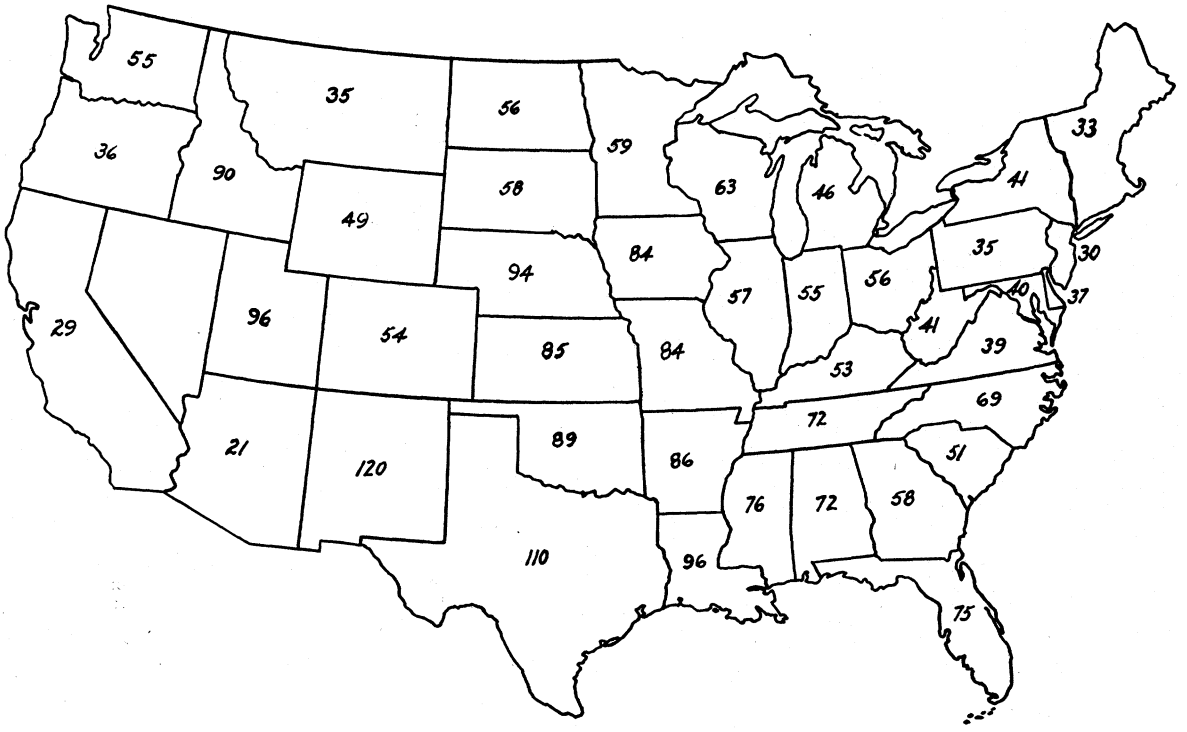

Fig. 1. Cumulative radioactive fallout in the United States from the spring of 1951 to 1 Jan. 1955, in millicuries of mixed fission products per square mile.

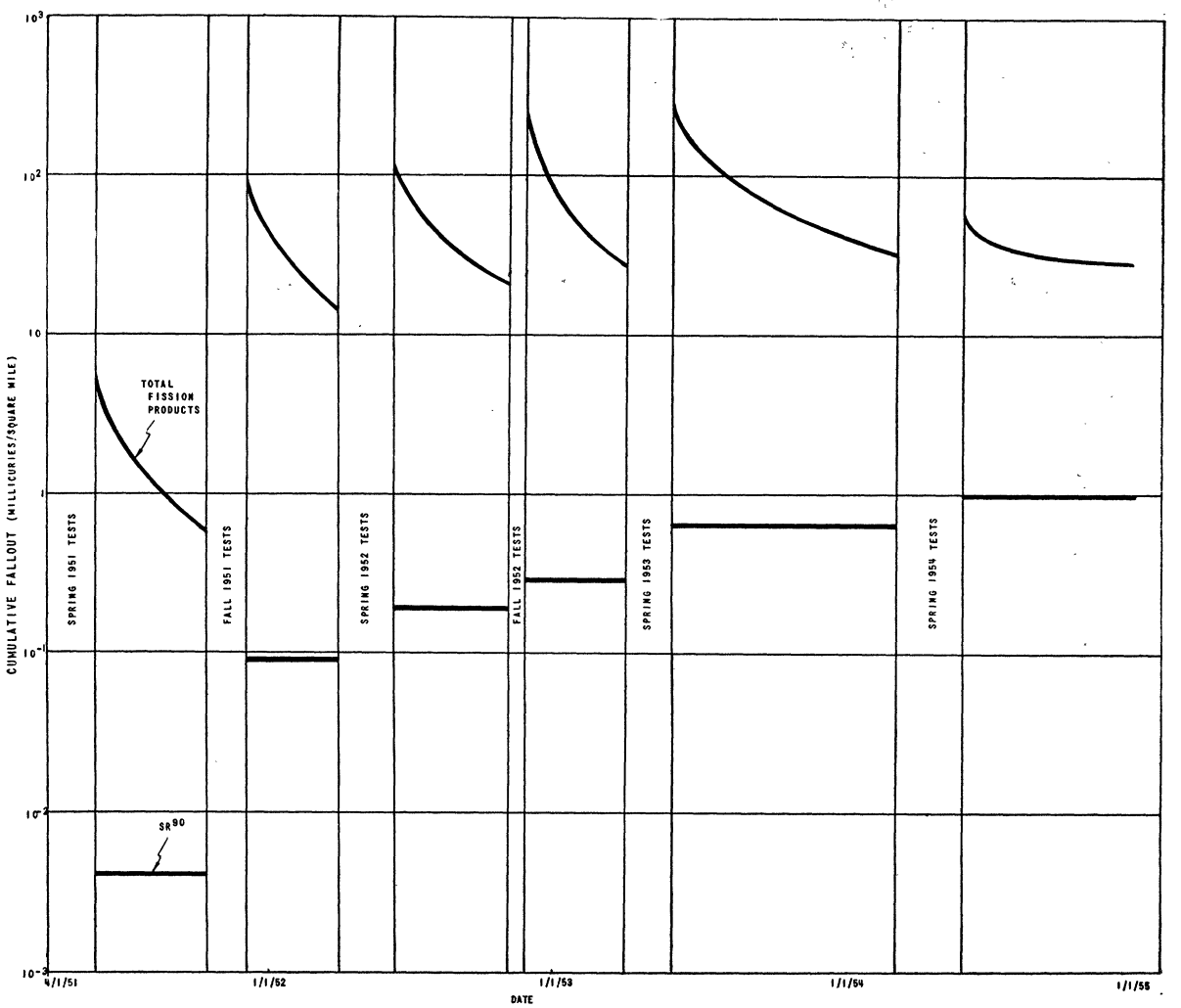

Fig. 2. Accumulation of fission products in the northeastern United States from tests made between early 1951 and 1 Jan. 1955.

the first atomic detonation in July 1945 was observed as a result of contamination of photographic packaging material (*11*). A number of scientists have recently recorded their observations in systematic fashion and a number of excellent scientific publications have resulted. Unfortunately, the calm presentation of the facts, usually many months after the incident, does not erase from people's minds the more sensational statements that have appeared in the press as a result of either pure speculation or superficial and incomplete information.

References and Notes

1. The work summarized in this report was performed by many individuals on the staffs of the U.S. Atomic Energy Commission and the U.S. Weather Bureau. We are particularly indebted to J. S. Alercio, A. E. Brandt, J. C. Bugher, N. Halden, H. D. LeVine, D. E. Lynch, and L. Machta.
2. M. Eisenbud and J. H. Harley, *Science* **117**, 141 (1953).
3. U.S. Atomic Energy Commission, *Thirteenth Semiannual Report* (Government Printing Office, Washington, D.C., Jan. 1953).
4. ———, *Fourteenth Semiannual Report* (Government Printing Office, Washington, D.C., July 1953).
5. Together with the stations operated within a distance of 200 mi from the test site, the total number of monitoring locations in the United States is more than 100.
6. "Radiation safety for A-weapons test," *Nucleonics* **10**, No. 5, 10 (1952).
7. The rad is a unit of dose equivalent to an energy absorption of 100 ergs/g.
8. H. F. Hunter and N. E. Ballou, *Nucleonics* **9**, C-2 (1951).
9. J. C. Bugher, "Medical effects of atomic blasts," paper presented at the 7th Annual Industrial Health Conference, Houston, Tex., 23 Sept. 1954.
10. H. M. Clark, *Science* **119**, 619 (1954).
11. J. H. Webb, *Phys. Rev.* **76**, 375 (1949).