Radioactive Dust from Nuclear Detonations

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DURING THE PAST TWENTY MONTHS there has been an increase in the tempo of atomic weapons tests. The original facilities of the Atomic Energy Commission's weapons testing program at Eniwetok Atoll have been augmented by the Nevada Proving Grounds, where nuclear detonations occurred in the winter of 1951, fall of 1951, and the spring of 1952.

With each of the programs in Nevada, there have been reports of transient increases in the radioactivity level in many communities of the United States and Canada. These increases are of interest to several groups not connected directly with the Atomic Energy Commission, including scientists engaged in low-level radiation measurements, uranium prospectors, and various segments of the photographic industry. The interest of the latter group began following the world's first atomic explosion in 1945, when Webb (*1*) reported abnormal radioactive contamination of cardboard packaging materials.

In order to assist these groups, as well as to gather scientific information, the Atomic Energy Commission has set up a monitoring program to measure the changes in radioactivity levels caused by nuclear detonations. The purpose of this communication is to describe briefly the monitoring system and to summarize some of the general conclusions that can be drawn from these studies.

Origin of the Increased Radioactivity Levels

The intense heat that accompanies the detonation of a nuclear weapon volatilizes the radioactive fission products as well as the various components of the weapon assembly. This mass of luminescent gas, which forms the "fireball," sucks up varying amounts of dust from the ground by convection. Although some neutron-induced activities may be present in this dust, it is essentially nonradioactive. A portion of the convected material may reach the fireball, and, depending on the existing temperature, some of this dust can be vaporized, or the dust particles can serve as nuclei on which the fireball vapors condense as a radioactive coating. Some of the vapors will condense around ionic nuclei and form discrete fume particles which may or may not aggregate with the larger particles of inactive dust.

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The total residual radioactivity from the fission products is now contained almost entirely within the head of a mushroom-shaped cloud originating from the fireball. This enormous amount of radioactivity (8.2×10^{11} curies γ-activity 1 minute after detonation of a weapon, equivalent to 20 kilotons of TNT) decays rapidly, and at any subsequent time the activity can be approximated by the relationship $A = A_1 t^{-1.2}$, where A_1 is the activity at one unit of time after the detonation (*2*).

The dispersion of radioactive particulates within the cloud is characterized initially by a wide range of particle size. Particles from less than 1 μ to about 10 μ in diameter are observed to be discrete spheres, whereas the larger particles are more apt to consist of fission products condensed on dust convected from the ground. Included in this portion of the dust are particles of relatively large diameter, often greater than 100 μ.

After the radioactive particles have been carried aloft to great heights (40,000 feet in the case of the Alamogordo explosion) and begin their descent to earth, they are subjected to lateral motion that depends on wind direction and speed. The manner in which a particle descends through various layers of the atmosphere, each characterized by its individual turbulent properties, is not well understood. A 100 μ particle, assuming a density of three, settles by gravity at a terminal velocity of 180 feet/minute; hence sedimentation may play a dominant role in the descent of the relatively large particles. However, a 1 μ particle of the same density will settle at approximately .02 feet/minute—a rate of fall that is not sufficient to explain the rapidity with which such particles reach the ground. It is likely that the turbulent behavior of the atmosphere is a more important factor in the descent of relatively small particles than is gravitational settling. The descent of particles of all sizes is greatly hastened in a region of precipitation where, as with other atmospheric dust, transport to the earth's surface may be accelerated in several ways.

Once they have settled to the surface, the particles may penetrate the earth by infiltration with raindrops. This may be either by simple particle transport or by the slight solubility of the particles.

The elevations in the radiation background observed following atomic detonations are due primarily to the deposition of radioactive dust on the earth's surface. This phenomenon has come to be known as "fallout." At any given location it can be described in terms of the increase in β- or γ-background, or by the quantity of settled radioactive dust (curies or equivalent units) deposited on a given area. In addition, the radiochemical properties of the dust, the concentration sus-

pended in air, and the particle-size distribution of both the suspended and deposited dust are properties that aid in characterizing the phenomenon of fallout and in evaluating its significance.

Description of Monitoring System

The monitoring system from which the data in this report are derived is designed to provide, during scheduled test periods, daily information concerning the presence of abnormal radioactivity in the area of the United States 200 miles and more from the test site. In general, the system comprises a network of 121 monitoring stations located at Weather Bureau stations across the nation and mobile teams equipped to undertake more intensive measurements in the region 200–500 miles from the test site.

Network of fixed monitoring stations. Because of the expense and technical difficulties that would be involved in equipping so large a network with radiation-detection instruments, observations are based on the collection of airborne and settled dust samples, which can be collected with relatively simple equipment and by uniform procedures.

The fixed monitoring stations sample the settled radioactive dust at ground level and, at some locations, the concentration of dust suspended in the air. Sampling is continuous, and once each day the collections are forwarded to the New York Operations Office, where the laboratory of the Health and Safety Division serves as the central counting facility. The dust is allowed to fall onto gummed paper, because this technique gives reasonably reproducible results, and particulates, even when entrained within raindrops, are effectively separated and retained on the gummed surface. At the New York laboratory, the samples are dry-ashed and measured for β-activity. Activities measured at the time of counting are then extrapolated, using the relationship previously given for fission products decay, to the midpoint of the sampling day, and the collection is reported as disintegrations/minute/square foot/24 hours.

The samples of airborne dust are collected on filter papers through which air is passed at a flow-rate of 20 cfm. The processing of the samples in the laboratory is similar to that described above, and the sample is reported as disintegrations/minute/cubic meter of air, representing the average concentration of activity over the 24-hour period.

Mobile monitoring teams. In order to obtain estimates of the maximum fallout in the annular ring 200–500 miles from the test site, mobile monitoring teams are utilized to assure that samples are collected immediately beneath the trajectory of the radioactive debris. The last four bursts in the spring tests in 1952, as well as certain of the tests in the fall of 1951, were monitored in this way.

Guided by meteorological observations made prior to and immediately following a detonation, the mobile teams are deployed at selected ground stations immediately beneath the predicted cloud trajectory. These teams are transported by air and ordinarily arrive at their sampling locations prior to the arrival of the radioactive dust. They sample continuously for a period up to 36 hours following a detonation. By this time the radioactive debris will have cleared the 200–500 mile annulus and, being more widely dispersed, can be adequately sampled by the fixed monitoring stations.

The equipment used by the mobile teams is identical

TABLE 1

List of Weather Bureau Stations Shown in Fig. 1

Code No.	Location	Code No.	Location
0-01	Avalon, Calif.	6-01	Marquette, Mich.
0-02	Los Angeles, Calif.	6-02	Sault Ste Marie, Mich.
0-04	Fresno, Calif.		
0-06	Reno, Nev.	6-03	Escanaba, Mich.
0-08	Elko, Nev.	6-04	Alpena, Mich.
0-09	Salt Lake City, Utah	6-05	Grand Rapids, Mich.
0-10	Flagstaff, Ariz.	6-06	Millbury, Ohio
0-12	Yuma, Ariz.	6-07	Fort Wayne, Ind.
		6-08	Vandalia, Ohio
1-00	Eureka, Calif.	6-09	Louisville, Ky.
1-03	Medford, Ore.	6-10	Nashville, Tenn.
1-08	Boise, Idaho	6-11	Alcoa, Tenn.
1-09	Pocatello, Idaho	6-12	Atlanta, Ga.
1-11	Rock Springs, Wyo.	6-13	Birmingham, Ala.
1-13	Grand Junction, Colo.	6-14	Montgomery, Ala.
		6-15	Mobile, Ala.
1-18	Albuquerque, N. M.		
1-19	Tucson, Ariz.	7-01	Rochester, N. Y.
		7-02	Buffalo, N. Y.
2-01	Ilwaco, Wash.	7-03	Dansville, N. Y.
2-02	Spokane, Wash.	7-04	Dunkirk, N. Y.
2-07	Great Falls, Mont.	7-05	Youngstown, Ohio
2-09	Billings, Mont.	7-06	Charleston, W. Va.
2-12	Rapid City, S. D.	7-07	Lynchburg, Va.
2-13	Scottsbluff, Neb.	7-08	Greenville, S. C.
2-16	Goodland, Kan.	7-09	Florence, S. C.
2-18	Amarillo, Tex.	7-10	Savannah, Ga.
2-19	Roswell, N. M.	7-11	Jacksonville, Fla.
		7-12	Tallahassee, Fla.
3-01	Williston, N. D.		
3-02	Bismarck, N. D.		
3-03	Huron, S. D.	8-01	Dexter, N. Y.
3-05	Norfolk, Neb.	8-02	Oswego, N. Y.
3-06	Concordia, Kan.	8-03	Syracuse, N. Y.
3-07	Wichita, Kan.	8-04	Albany, N. Y.
3-08	Wichita Falls, Tex.	8-05	Binghamton, N. Y.
3-09	Abilene, Tex.	8-06	New York, N. Y. (La Guardia Field)
3-10	Del Rio, Tex.		
4-01	Fargo, N. D.	8-07	New York, N. Y. (AEC Office)
4-02	St. Cloud, Minn.		
4-03	Rochester, Minn.	8-08	Harrisburg State Airport, Pa.
4-04	Des Moines, Iowa		
4-05	Columbia, Mo.	8-09	Wilmington, Del.
4-06	Fort Smith, Ark.	8-10	Baltimore, Md.
4-07	Texarkana, Ark.	8-11	Richmond, Va.
4-08	Port Arthur, Tex.	8-12	Washington, D. C.
4-09	Corpus Christi, Tex.		
5-01	Green Bay, Wis.	9-01	Caribou, Me.
5-02	Milwaukee, Wis.	9-02	Eastport, Me.
5-03	Terre Haute, Ind.	9-03	Mt. Washington Observatory, N. H.
5-04	Memphis, Tenn.		
5-05	Jackson, Miss.		
5-06	New Orleans, La.	9-04	Providence, R. I.
5-07	Peoria, Ill.	9-06	Boston, Mass.

FIG. 1. Radioactivity deposited from tests in spring 1952. Large figures: disintegrations/min/sq foot on Jan. 1, 1953; small figures: station code (see Table 1).

with that provided for the fixed monitoring stations, except that cascade impactors for particle size analysis of the airborne dust are available, as are instruments for measurement of radiation background.

Findings During Tests in the Spring of 1952

The test program conducted in Nevada during the spring of 1952 was a series of eight detonations beginning on April 1 and ending June 4. During this period more than 30,000 samples were collected and evaluated as part of the nationwide monitoring program, and the principal observations and conclusions pending the preparation of more detailed analysis are presented herewith.

Cumulative distribution of deposited radioactivity. Fig. 1 presents the cumulative distribution of deposited radioactivity from the eight explosions in disintegrations/minute/square foot. The data were obtained by extrapolating the activities reported for each of the daily collections to the arbitrary date January 1, 1953, and then summing the extrapolated results from each station. These data thus present the total activity deposited on the surface of the ground as of the given date. Equivalent values for earlier dates can be computed by the factors given in Table 2.

In general, the total fallout shows a geographical variation of two orders of magnitude from 10^2 to 10^4. The area of highest deposition extends northward from the Proving Grounds and includes the stations in northern Nevada and Utah, Idaho, and Montana. The fallout in Salt Lake City occurred almost entirely on one day, May 7, when the passage of the radioactive cloud over Salt Lake City and the surrounding area coincided with rainfall in the region. For the 24-hour period beginning 1130 MST on May 7, the fallout at Salt Lake City was measured at 8×10^6 d/m/ft^2.

TABLE 2

Conversion Factors for Fig. 1

Date	Factor
1/1/53	1
11/1/52	1.4
9/1/52	2.4
8/1/52	3.7
7/1/52	7.4

The fixed monitoring network was arranged in rough arcs centered on the Proving Grounds. The station code numbers are prefixed from 0 to 9, according to the distance from the origin. The mean values for these groups of stations are plotted in Fig. 2. These data fit a smooth curve, except that the values for classes 5 and 8 are high. The maximum activity for each group of stations is also given, and in each class these values are two to four times the mean. A more complete interpretation of the findings must await

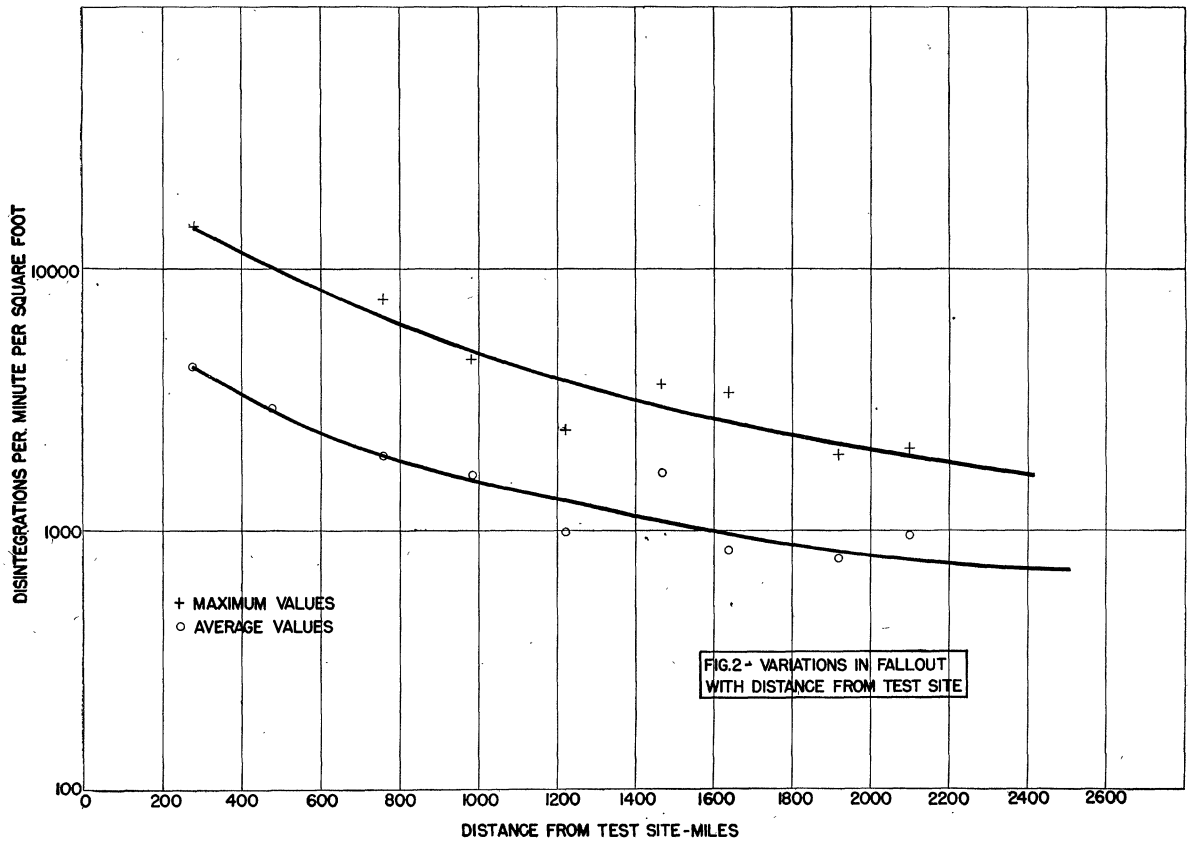


FIG. 2 - VARIATIONS IN FALLOUT WITH DISTANCE FROM TEST SITE

TABLE 3

SUMMARY OF DATA FROM LOCATIONS AT WHICH MAXIMUM FALLOUT WAS OBSERVED BY MOBILE TEAMS

Burst	Airborne dust			Settled dust	
	Locality	Maximum concentration (disintegrations/min/cu meter)	24-Hr av concentration (disintegrations/min/cu meter)	Locality	24-Hr fallout (disintegration/ft²)
5/ 7/52	Ogden, Utah	510,000	45,000	Wendover, Utah	32×10^6
5/25/52	Price, Utah	27,000	2,200	Grand Junction, Colo.	1×10^6
6/ 1/52	Elko, Nev.	360,000	53,000	Elko, Nev.	4×10^6
6/ 5/52	Elko, Nev.	620,000	30,100	Boise, Idaho	8×10^6

study by the Weather Bureau, where the data are now being analyzed in relationship to meteorological factors.

Measurements by mobile monitoring teams 200–500 miles from proving grounds. Data provided by the fixed stations within the 200–500 mile annulus are augmented by the observations of mobile monitoring teams, which were deployed beneath the trajectory of the radioactive cloud. The initial height of the cloud and the rate of descent of the particles, combined with the lateral motion caused by winds, produce a "skip distance" such that the region of maximum fallout is commonly near the central or outer regions of the annulus. Not only does the fallout diminish at greater distances from the proving ground, but also at closer distances, until one approaches very close to the site of detonation.

Data from the mobile team reporting maximum fallout for each of the four bursts are given in Table 3. The highest concentration of airborne radioactivity does not always occur at the locality having the maximum fallout as measured by settled radioactivity. This is easily understood when it is recognized that the method of collecting dust suspended in air at ground level excludes raindrops that sometimes entrain radioactive particles from higher altitudes. Moreover, a lack of correlation between airborne and settled dust can be attributed to differences in particle size: one extreme limiting case would be a suspension of rapidly falling particles that are too large to be deflected into the air-sampling device or, at the other extreme, a dense suspension of particles too small to be influenced by gravitational settling. The first would appear only as settled dust, whereas the second would appear only as airborne dust. Neither extreme is probable.

Comparison of findings with data from previous weapons tests. The fallout during these tests was slightly higher than the fallout measured during the series in late 1951. The tests held at Eniwetok in early 1951 caused less fallout in the United States than either of the two continental test series for which data are available.

The decay rate of the radioactive dust from each burst of a series follows the exponential time function given previously. During the period of the test program and for a short while thereafter, the decay rates of debris from the successive bursts are markedly different at any given time. As the period of time from the last burst becomes long in relation to the interval between the first and last burst, the decay curves approach a uniform slope and it is possible to consider the accumulation of debris from all bursts as being the same age. Thus, with negligible error, one might arbitrarily select the midpoint of a four-week test program as the time of detonation for all bursts and present in a single decay curve activity vs. time for an indefinite period beginning 60 days from the end of the test series. In Fig. 3 the average fallout in the northeastern United States from each of the three test programs is plotted in this way.

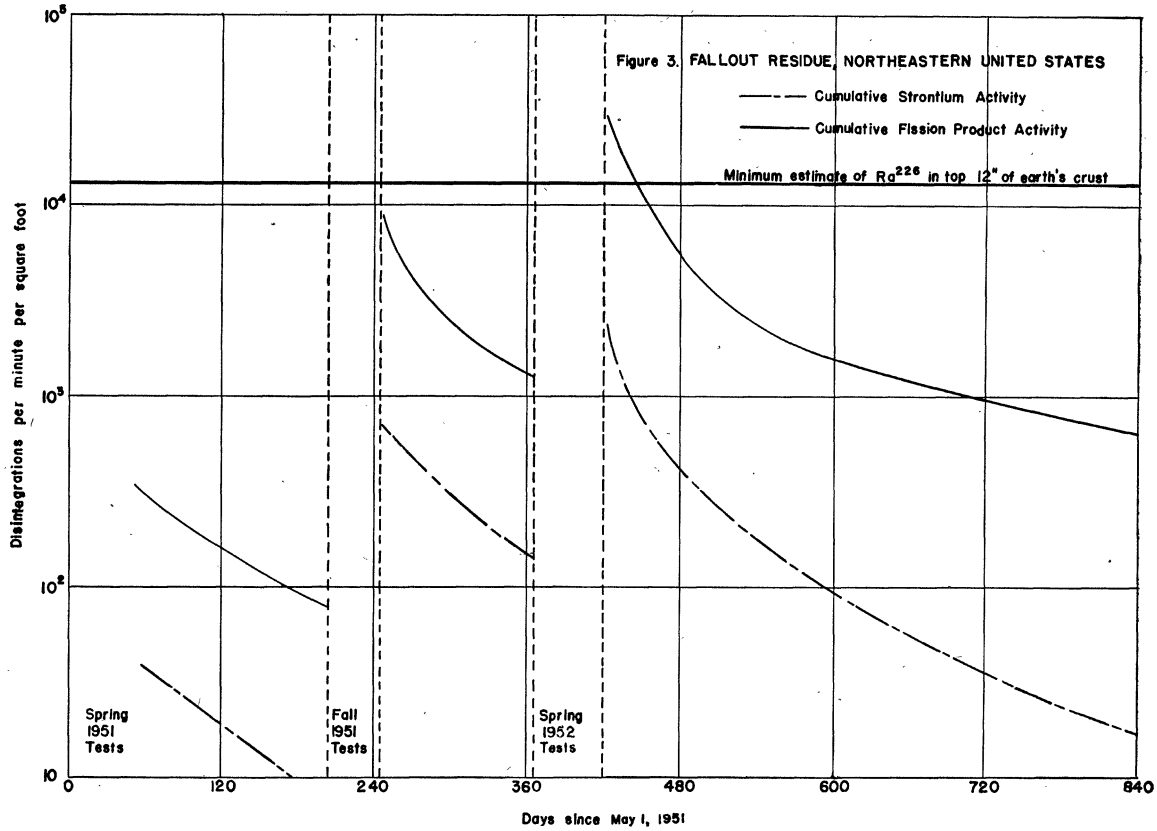
The fallout in this region, from the tests conducted at Eniwetok early in 1951, was of a lower order than that observed for the two Nevada series. Within approximately 200 days this activity had decayed to a level that was no longer significant in comparison with the radioactivity present from the second of the three series. The total activity deposited on unit areas of the earth's surface during the period beyond approximately 200 days, and until the start of the third series, can thus be estimated by the decay curve representing the second test series.

The fallout from the third and most recent series, being of the same order but slightly higher than the second series, is also given. Coexisting on the earth's surface is the fallout from the previous tests, the total being given by the upper decay curve, which thus approximates the activity now present from all three series of tests. The curves are extended until approximately January 1, 1954.

SIGNIFICANCE OF DATA IN RELATION TO THE NATURAL RADIOACTIVE BACKGROUND

A comparison of these data with naturally occurring radioactivity offers a useful means of appreciating the meaning of the data, particularly with regard to their biological significance. Natural radioactivity originates from cosmic sources and from the naturally occurring radioisotopes, of which Ra^{226}, its daughter products, and K^{40} are the most important.

The average concentration of Ra^{226} in soil is of the order of 10^{-13} to 10^{-12} curies/g. Taking the lower concentration as a conservative basis for comparison and limiting our consideration to the top 12 inches of the soil, one calculates that Ra^{226} produces 13,000 d/m/ft² —about 30 times greater than the total residual activ-



ity estimated to be present from the three test series on January 1, 1953. If one includes the entire uranium series, the thorium series, and radiopotassium, a reasonable estimate of the activity naturally occurring in the upper foot of the earth's crust is 10^5 d/m/ft^2.

An estimate of the total activity expressed in this way has little meaning, because it represents the total rate of disintegration of α-, β-, and γ-emitters. Moreover, a comparison of this total with the activity caused by residual fission product radiation is not valid per se, because one must consider the chemical properties of the individual isotopes and the manner in which they enter into biological systems. Of the long-lived fission products, the isotopes Sr^{89-90} are most likely to be absorbed into the body from soil or water, in which fission products are present because of the similarity of strontium to calcium and radium. An estimate of the long-term hazard resulting from the biological uptake of residual fission product activity may therefore be based on a comparison of the strontium component of the fission products with naturally occurring Ra^{226}. The lower decay curve in Fig. 3 plots the activity caused by radiostrontium. This curve is computed from the total fission product decay using data collected by Hunter and Ballou (*3*). The residual radiostrontium is seen to be of a low order compared to the most conservative estimate of the concentration of naturally occurring radium.

Fig. 3 is calculated from the observations of fallout in the northeastern United States, where the mean deposition is approximately 10 per cent of the fallout in areas closer to the Nevada test site. The fission product activities of Fig. 3 should therefore be multiplied by a factor of 10 for an approximation of the residual radioactivity for the regions of maximum fallout.

The fallout measurements are given in disintegration rate units because of the technical difficulties and expense that would be involved in making continuous low-level radiation measurements at a large number of geographically scattered stations. The settled dust measurements do, however, lend themselves to conversion to roentgen equivalent units with the use of data from *The Effects of Atomic Weapons* (*2*). Among the difficulties involved in such a conversion is the fact that the spectral properties of the radiations from mixed fission products are changing constantly with time. For this reason the dose rate from a given activity of fission products is dependent on their age.

Some data are available from measurements made by the mobile monitoring teams. The highest β-γ intensities, measured 3 feet from the ground, were in the range 10–20 mrep/hr, the γ-component being about 10 per cent of the total. These were maximum values associated with fresh deposits of fission products of age 7–15 hours. When the dose delivered by this rapidly decaying activity is integrated from the time of fallout to infinity, the total exposure is ap-

proximately 50 milliroentgens. The γ-dose from *natural* sources is approximately 2 mr/day (*4*). The integrated exposure to the radiation from deposited fission products, under the worst conditions observed, is thus no greater than the dose received from natural radioactivity in a period of 25 days. The present accepted maximum permissible radiation dose rate is 300 mr/week, so the integrated dose from fallout is one sixth that allowed in a week.

As in the case of radioactivity deposited on the earth's surface, the biological significance of radioactive dust suspended in air can likewise be discussed in relation to the radioactivity that is normally present. The airborne dust associated with fallout remains in a given locality for only a few hours, during which its influence on the background radiation level is of a lower order than the rise in background resulting from material deposited on the surface. However, in the case of airborne dust, we must consider the magnitude of the radiation dose to the lung from inhalation of the radioactive particles.

The natural radioactivity of the atmosphere originates almost entirely from radon, which has diffused from the earth. Unpublished measurements in this laboratory indicate that 5×10^{-14} curies/liter of air is a conservative estimate of the radon concentration in normal air. The concentration varies with both geographical and meteorological factors, and is frequently as high as 5×10^{-13} curies/liter. This radioactive gas is present in equilibrium with its daughter products which, because of their initial charge, characteristically adsorb on inert atmospheric dust (*5*). When inhaled, a fraction of this dust is temporarily retained in the lung, and some concentration of the naturally occurring radioactive daughter products of radon is thereby effected. Based on calculations made by Bale (*6*), a radon concentration of 5×10^{-14} curies/liter, in equilibrium with its daughter products, results in a daily lung dose of 10 mrem (assuming a factor of 20 for the relative biological effectiveness of α-particles).

With an approximation of the natural radiation dose to the lung as a basis for comparison, one can now examine the significance of airborne fission products. From Table 3, the highest average concentration of radioactivity observed during a 24-hour period was 53,000 d/m/M^3 at Elko, Nevada. The mass median diameter of this dust was approximately 2 μ, which is in the region of optimum particle size for maximum retention in the lung (*7*). The cumulative dose to the lung was calculated (*8*), with assumptions that (*a*) 50 per cent of the dust is retained initially, (*b*) 50 per cent is eliminated from the lung every 90 days, (*c*) the lungs weigh 1000 g, (*d*) the radioactive dust irradiates the lung uniformly, and (*e*) an individual inhales 10 cubic meters of air in the 24-hour period. The approximation of the cumulative dose thus obtained is 20 mrem, equivalent to the dose from the inhalation of normal atmospheric radon daughter products during a two-day period. As was true for whole body irradiation, the dose to the lung from inhaled fission products for maximum fallout is minute when compared to the exposure received in the course of a lifetime from natural sources of radioactivity.

Conclusion

The increases in background radiation sometimes observed at considerable distances from the site of nuclear detonations are due to the deposition of traces of radioactive dust. For brief periods immediately following a detonation, the radioactive background can be markedly increased in some areas, but the cumulative dose from such depositions are minute because of the rapid decay of the activity. The long-lived components of the radioactivity are of a low order compared with the natural radioactivity of the earth's surface and atmosphere.

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News and Notes

Eighth Conference on Iroquois Research

The eighth annual gathering of Iroquoianists, held at Red House, N. Y., Oct. 10–12, again brought together several dozen scholars and scientists from the disciplines that maintain an interest in the anthropology and history of the Iroquoian-speaking Indians of eastern North America. The theme of this year's conference was "Ethnohistory," a choice dictated by the consideration that the Iroquois Indians appear in written accounts from the sixteenth century to the present day. Of necessity, Iroquoian studies have traditionally had a historical consciousness that is impossible for investigations of less adequately documented aboriginal populations. Aware of the widespread interest in a *rapprochement* of history and the social sciences, the program committee (Anthony F. C. Wallace, *chairman*; Martha Randle, John Witthoft, and George Snyderman) felt that discussion of problems and opportunities in Iroquois ethnohistory