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Made in United States of America
Reprinted from THE SCIENTIFIC MONTHLY
Vol. [illegible], No. [illegible], December, 1955

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Reprinted from The Scientific Monthly
Vol. 81, No. 6, December, 1955

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DURING the past decade the United States has conducted a program of nuclear weapons development and testing. The release of energy equivalent to thousands and millions of tons of TNT, together with the production of large quantities of radioactive materials must be inherently accompanied by some degree of risk. Since the continuation of our nuclear testing program is mandatory to the defense of our country, the problem then becomes one of *defining* these risks and of *evaluating* them in the light of what is best for the peoples of the free world.

The information given here provides answers toward three basic questions raised concerning the testing of nuclear weapons: (i) What are the problems and possible risks associated with nuclear weapons testing? (ii) What are the data concerning effects from past tests and what might they be if the tests are continued? (iii) What do these data mean—how serious are the possible risks?

Blast and Thermal

Blast. The blast effects are limited to areas near the site of detonation. Partial damage to structures may extend for about 2 miles for a nominal-sized bomb (equivalent in energy to 20,000 tons of TNT) (*1*) and for 10 miles or more for high-yield weapons. However, reflection of blast waves from layers of the atmosphere may focus the blast wave producing greater pressures than are usually expected at that point (*2*). These reflected waves have caused some structural damage outside of the Nevada Test Site. Total claims paid to date for such damage amount to $44,342.18. No person has been injured directly or indirectly from these test blasts. Thus, there is some slight risk of minor structural damage such as broken windows in areas around the Nevada Test Site, but the blast pressures outside the site will have no direct detrimental effect on human beings and animals.

Thermal. Significant amounts of heat radiation may be received out to 2 miles from a nominal bomb (*1*) and about 20 miles for a high-yield weapon. Also, at the time of a nuclear detonation the light produced from a nominal bomb may temporarily blind a person if he looks directly at it, even from a distance of 30 to 40 miles. The brilliance of a nominal bomb rivals that of 100 suns when viewed at a distance of 6 miles (*1*). The simple act of turning the head away from the line of detonation can give adequate protection. For these reasons, motorists near the Nevada Test Site are warned prior to each detonation. In the past, four military personnel participating in the Nevada tests have received eye injury—three superficial that have completely healed, and one serious. No one has been injured off the test site.

Radiations

External exposure. At the time of detonation the almost instantaneous gamma rays released will be of concern out to about a mile for a nominal bomb (*1*) and out to a few miles for high-yield weapons. However, significant amounts of radioactive fallout may occur at more than 300 miles downwind from high-yield weapons. This material emits gamma rays similar to the instantaneous ones but with less quantum energy.

About 25 roentgens of gamma radiation, delivered in a short time (about a day or less) over the whole body, are required to produce minor and transitory changes in the blood; about 100 roentgens are required for some persons to show radiation sickness; about 450 roentgens may be lethal to half of the exposed persons (*3*). (A roentgen is a unit for measuring the amount of radiation, or dose, that has been received. For example, a normal x-ray will deliver about 1/10 roentgen or more to the chest; about 10 roentgens are received in a lifetime from cosmic rays and from naturally occurring radioactivity in the air, water and soil, *4*).

The highest radiation exposure to any individual in the United States outside the Nevada Test Site has been about 7 roentgens (about 12 people) and for any community about 4 roentgens (*5*). These dosages are below the amount needed to produce any detectable effect and are far below the amount required to result in radiation sickness.

Following the 1 March 1954 thermonuclear detonation at the Pacific Proving Ground, an unexpected shift of the winds caused a heavy fallout over some of the Marshall Islands. The highest radiation exposure to the inhabitants of these islands was about 175 roentgens. Most of these people experienced radiation sickness, but there were no deaths. It was reported by the Japanese that some fishermen aboard a vessel near the Pacific Proving Ground on the same date received a higher exposure than this. They further reported that one of these fishermen died on 23 September 1954 from severe hepatitis. (Hepatitis is a condition not directly attributable to radiation.)

Fallout material also emits beta rays that travel at most a few meters in air and are of principal concern when highly active fallout material remains in contact with the skin for relatively long periods of time. This may result in skin damage that would appear like a burn and may ulcerate if the radiation exposure has been large enough (*6, 7*).

Beta burns occurred on the skin of the Marshallese exposed to the fallout described in the preceding paragraph. Also, some cattle in 1945 and 1952 and some horses in 1953 experienced skin burns caused by the beta radiation from the fallout material being in contact with their skin following continental tests. All were within 20 miles of ground zero. Cattle from the 1945 exposure have been under observation at Oak Ridge. There have been no observable changes in the animals, except skin damage and loss of hair in spots that regrew but was gray in color. Their offspring have been normal in all respects.

These experiences have shown the need for larger warning areas when high-yield weapons are to be detonated. These are now established during operational periods; and with the continuing improvements in weather prediction, there is essentially no risk of hazardous amounts of fallout outside the control areas in the Pacific and continental United States.

Internal exposure (short term). Radioactive iodine present in fallout material may find its way into the body through ingestion or inhalation and will concentrate in the thyroid gland.[1] There are several forms of radioiodine all similar in their radiation effect on the tissues but differing in half-life (the time required for the material to lose one-half of its radioactivity.) The half-life of the longest one of biological concern is only 8 days, however, so that the problem is one of short-term effects.

Because of their eating habits, grazing animals ingest materials over a relatively large area, which means that significantly larger amounts of radioactive iodine reach the thyroid. This gland is composed of tissue that is relatively insensitive to radiation. Experimental studies with sheep, for example, show that about 16,000 roentgens are required to produce even minimal changes in the cell structure and about 50,000 roentgens are required to produce definite cell damage and hypothyroidism (*8*).

The highest amount of radioactive iodine found in any animal due to fallout was in some sheep grazing near the Nevada Test Site during the spring of 1953. The estimated radiation dose to their thyroids was about 2000 roentgens (*9*). Owing to the [illegible] widespread distribution of fallout from the Pacific tests in the spring of 1954, radioactive iodine was found in the thyroids of cattle and sheep in various parts of the United States (*10*). The highest total radiation dose to the thyroid from this series was estimated to be about 40 roentgens. The peak thyroid measurements in animals during the 1955 test series were about 5/1000 roentgen per day (*9*).

Radioactive iodine in the thyroid of human beings resulting from intake of fallout material has been measured. The highest radiation exposure measured was in individuals near the Nevada Test Site in the spring of 1955, but there is some uncertainty in the readings, owing to general contamination of the environment. However, if *all* the observed radiation is ascribed to radioactive iodine in the thyroid, the exposure amounted to a peak value of a few thousandths of a roentgen per day (*9*). The peak values for other human measurements in the United States for tests both in Nevada and in the Pacific have been generally one-tenth or less of this level.

These data indicate that the highest measured radiation dose to the thyroids of animals has been below the level that might produce harmful effects and that the highest measured radiation exposure to the thyroid of human beings has been far below that needed to produce any detectable effects.

Internal exposure (long term). One of the biologically important elements in fallout is strontium-90. If it is taken into the body, it is selectively deposited in the bones and continues to irradiate the surrounding cells for long periods of time, since it has a half-life of about 27.7 years. The deposition of relatively large amounts of strontium-90 in the bone would be expected eventually to produce bone tumors (*11*).

Owing to its relatively long half-life the amount of strontium-90 will accumulate in the environment if more is continually added. Assuming a constant rate of yearly addition and no loss through weathering, an equilibrium condition would be approached after 150 years—a state in which the rate of addition is equal to the rate of loss through radiological decay. About one-half of this equilibrium amount would be reached in 28 years. The equilibrium amount would be about 40 times the annual addition.

At the present time the average contamination of strontium-90 in the United States is about 15/100,000 microcurie per square foot. (A microcurie is a unit for measuring the radioactivity of a material. By definition, a curie is 3.7×10^{10} disintegrations per second; a microcurie is one-millionth of a curie.) This is about 1/240 of that of the soil's normal radium content (*12*) and 1/300 of the amount (*9*) estimated to result eventually in the body's accumulating a maximum permissible body burden of strontium-90—a value considered safe.

If it is assumed that future nuclear tests would result in an *annual* fallout equal to the *highest* amount experienced heretofore in any one year, then the projected average for the United States after a period of more than 150 years might approach 13/10,000 microcurie per square foot (*9*). This is about 1/27 of the amount of radium that is usually present and 1/150 of the amount estimated to result eventually in the body's accumulating a maximum permissible body burden of strontium-90—a value considered safe. These possible trends will be continually checked by the Atomic Energy Commission's extensive monitoring program now in operation.

Neutrons (particles) that are released from a nuclear detonation react with a nitrogen atom in the air to form radioactive carbon, called carbon-14, which has a long half-life of about 5600 years. This radioactive carbon enters into the biosphere (the environment of living things) alongside normal carbon and thus finds its way into all living tissues and irradiates the surrounding cells. Since carbon is found in all living matter, the effects are similar to those when the whole body is irradiated by an external source.

Because of its long half-life the amount of carbon-14 in the world would accumulate until it reached an equilibrium state, a condition in which the rate of production is equal to its rate of loss by radioactive decay. Assuming a constant rate of production through yearly nuclear tests, an equilibrium condition might be approached after 30,000 years. One-half of the equilibrium value would be reached in 5600 years.

A nominal-sized bomb produces about 1/48 pound of neutrons (*1*). If it is assumed that each neutron will react with a nitrogen atom to produce carbon-14, then the total amount of this element produced would be about 1/3 pound. It has been suggested that a large thermonuclear weapon might produce as much as 140 pounds of carbon-14 (*13*). Accepting the foregoing estimates, if several large thermonuclear detonations occurred every year for 30,000 years, the near equilibrium amount of carbon-14 thus created in the world would be about 20 times greater than the amount now present.

There are about 180,000 pounds of carbon-14 maintained currently in nature in an equilibrium state, owing to natural production by neutrons (created by cosmic rays) reacting with nitrogen of the air (*14*). However, this amount contributes only about 1 percent to the total natural radiation dose received by the body (total natural radiation is about 3/1000 roentgen per week) (*15*). Thus, the equilibrium amount of carbon-14 (approached in 30,000 years) might increase the normal radiation dose to the body by 20 percent of the present value (*9*). The conclusion must be made that this effect is inconsequential.

Air, water, and fish. Air and water usually contain more than one naturally occurring radioactive substance (radon, thoron, radium, potassium, and so forth) (*16*). Inhalation of these radioactive materials present in the air results in a radiation dose of 3/100 to 8/100 roentgen per week being delivered to the lungs. The radioactive content in water supplies varies greatly, but some has been found in essentially all sources. Rain will be radioactive, owing to the natural radioactive materials in the air. Not only is radioactivity found in air and water, but the amounts vary widely from place to place and time to time.

After the detonation of a nuclear device, some of the radioactive particles are small enough to remain in the air for long periods of time and thus to be carried by the prevailing winds over large areas. These particles may be inhaled, and also they may find their way into water and food supplies and thus be swallowed. A certain fraction of radioactive elements taken into the body are absorbed from the lungs and intestinal tract and deposited in various organs of the body. They are eliminated from the body—some rapidly, some very slowly—and as long as they remain in the body they irradiate the surrounding cells. The problem of inhalation and ingestion of radioactive materials fundamentally is no different from that of living in an environment of external radiation; hence, the problem is to determine what would be the radiation exposure, or dose, to the living cells of the body. The values that have been recommended by various expert groups for the maximum permissible concentration of radioactive materials in air and water are based on this consideration (*17*).

The highest activity observed in air anywhere in the United States (outside the control area in Nevada) has been about 1.3 microcuries per cubic meter of air averaged over the 24-hour period that the activity was present (*18*). The estimated radiation dose to the lungs resulting from this activity was about the same as would be expected from breathing air containing normal amounts of radioactive substances for a period of less than a month (*19*). The highest activity found in water in the United States has been about 1/7000 microcurie per 1/1000 liter (about 1/1000 quart) at 3 days after the detonation (*19*). This is about 1/36 of the maximum permissible amount—a quantity considered safe—even if the water had been stored and used as the sole source of supply for a lifetime (*12*).

Radioactive materials have been found in plankton and algae in higher concentrations than in the surrounding water. When fish eat these marine organisms, a small fraction of this radioactivity is retained within the fish. Fish containing greater than maximum permissible amounts of radioactivity (based on the assumption that they will be used as a principal source of food) have been found at the test atolls of Bikini and Eniwetok and in the nearby areas of heaviest fallout. Since it is the total amount of ingested radioactive materials (of known isotopic content) that is important, a limited quantity of fish containing above-maximum permissible concentrations might be eaten safely, but their continual consumption would be undesirable.

The presence of such radioactivity in tuna fish was reported by the Japanese following the Pacific test in the spring of 1954. The highest activity reported by the Japanese was found on the skin of the fish aboard the vessel *Fukuryu Maru* (*Fortunate Dragon*). This was the ship that received the direct fallout on the day of detonation, 1 March 1954, and the source of the radioactivity measured on the fish was principally the direct surface contamination as the fish lay aboard the vessel. The quantitative levels of activity found on these fish are unknown, but thereafter the highest activity was 1300 counts per minute measured by a Geiger counter, with shield open, held close to the surface of the fish. This latter activity is considered safe for unlimited consumption, by American permissible standards.

Genetics. There are five relevant points concerning radiation and genetics that may be enumerated.

1) Radiation can cause irreversible inheritable changes (called gene mutations) in the germ cells. Most of these mutations are considered harmful.

2) The number of mutations produced is independent of the rate of radiation exposure; that is, it is the total exposure to a given kind of radiation that is the important factor.

3) Radiations have not produced any kinds of mutations not already known and occurring naturally. Thus the possible effects of irradiation from nuclear detonations rightfully may be compared with those produced by natural causes.

4) If the mutation that occurs is of the "dominant" type, then the effect appears in the first generation. It is believed, however, that by far the largest number of mutations that do occur are of the "recessive" type that may be carried generation after generation without expression until it is matched by a similar mutant gene in the opposite sex—an occurrence of very low probability in a general population such as ours that is out-breeding (owing to taboos against marriage of close relatives). Thus the presence of a mutant gene very rarely means a "defective" individual in the sense of detectable defects.

5) It has been estimated that natural causes (of which radiation from normal sources accounts for only 10 to 20 percent) (*20*) may produce on an average two additional mutations among every five individuals. Since we receive mutations from both parents, we may have on an average four "new" mutations in every five individuals, in addition to the very numerous "old" mutations inherited from

earlier generations (*21*). An estimate has been made by some that about 80,000 mutations may be present among the populace in the United States living 100 years from now owing to radiation exposure from all nuclear tests to date.

The average radiation exposure to people in the United States from all nuclear detonations to date has been about 1/10 roentgen (*9*). (This is the result of external radiation. Additional exposure of the gonads to any radioactive fallout taken into the body would be insignificant.) This is in addition to the approximately 7 roentgens that may be expected from natural sources over a reproductive lifetime—that is, an increase of 1/70 of the normal amount of radiation. If 80,000 mutations will be present in the population of the United States 100 years from now as a result of radiation exposure from all nuclear tests, then by the same calculations about 120 million (1500 times as many) additional mutations may be produced by natural causes during the same 100 years, assuming no increase in population over the 1955 census (*9*).

If it is assumed that future nuclear tests would result in an *annual* fallout equal to the *highest* amount experienced heretofore in any one year, then the average radiation exposure to people in the United States would be about 1/7 of that from natural causes and might increase the normal rate of mutations by 1.4 to 2.8 percent. If it is assumed that an average of two additional mutations are produced by natural causes among every five individuals, the new mutation rate might be 2.03 to 2.06 per five persons (*9*).

It is generally held that an increase in mutation rate is undesirable. These data and estimates give some perspective concerning the *degree of* risk involved.

Weather

There has been speculation on the part of some regarding the possible relationship between test nuclear detonations and the weather. Some of the effects suggested have been: i) the particles of dust being thrown up by the detonation acting in a manner similar to silver iodide crystals used in cloud seeding to initiate precipitation; (ii) the change in the electric properties of the atmosphere owing to ionization produced by the radioactive particles; iii) the reduction of direct solar energy received on earth owing to the dust thrown into the air by the detonation; (iv) the increase in number of tornadoes; and (v) the occurrence of drouth in the southwestern United States.

It is true that, following large nuclear detonations, minor weather changes, such as local cloud formation, sometimes with local precipitation, have been noted in the Pacific where the moisture conditions in the atmosphere were most favorable for this effect. However, experiments conducted by Air Force Cambridge Research Center on nucleating (cloud seeding) properties of Nevada dust and ionizing properties of radioactive fallout and studies made by the U.S. Weather Bureau on possible effects of nuclear detonations on electric properties of the air, solar radiation, tornadoes, and precipitation show the following (*22*).

1) Nevada dust has very poor nucleating properties; that is, ineffective as a cloud-seeding agent.

2) The amount of ionization produced by radioactive material is insignificant in affecting general atmospheric conditions.

3) Whereas, even relatively minor volcanoes may put enough dust into the atmosphere to decrease measurably the amount of direct solar radiation at the observation point established, no such decrease has been observed from any nuclear detonation.

4) Much of the increase in tornado reports during the past 5 years can be traced directly to the improved methods of reporting tornadoes that normally occur.

5) The present drouth in New Mexico began before the nuclear tests were started in Nevada. Similar drouths are on record for the 1930's and for earlier dates.

Thus the data and their evaluation to date present no evidence that nuclear detonations affect the weather, except as noted here for large detonations in the Pacific.

Nitric Acid Formation

At the time of a nuclear detonation, a minute fraction of the energy released causes nitrogen and oxygen of the air to combine, producing nitrogen dioxide, which in turn becomes nitric acid by uniting with water vapor. This acid may be brought to the earth by rainfall. The amount of nitrogen dioxide that persists following a nuclear detonation is less than what might be predicted on the basis of energy considerations alone, because the temperature of the fireball remains high for a relatively long period of time as compared with lightning, thus allowing some of the nitrogen and oxygen to dissociate (*1*).

It has been speculated by some that the amount of nitric acid formed from the detonation of a high-yield nuclear weapon equivalent to millions of tons of TNT would be great enough to produce an acidity of *p*H 5 in rainfall. (*p*H is the measure of acidity. A *p*H of 7 represents neutrality; the lower the number, the greater the acidity.) However, nitric oxides are added normally to the air by decomposition of organic matter in the earth and to a made lesser degree by nitrogen and oxygen in the air combining under the influence of lightning (23). Thus, it has been found that the acidity (pH) of normal rain has average values of 4 to 5, which is more acid than that predicted by some for rain following the detonation of high-yield weapons.

Even if the assumption is made that nuclear bombs have a high degree of efficiency for nitric acid formation, then a nominal-sized bomb (20,000 tons of TNT equivalent) might produce 100 tons of nitric acid. It would require about four nominal-sized bombs detonated each day to equal the normal rate of addition of nitrogen dioxide to the air in Los Angeles county (*9, 24*). It would be necessary to detonate every day a nuclear weapon releasing the equivalent of 35 million tons of TNT to equal the normal rate of production of nitric acid in the world (*9*).

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