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THE BIOLOGICAL HAZARDS OF NUCLEAR WEAPONS TESTING

-- An Attempt to Reconcile Divergent Views --

A Report by the F A S Radiation Hazards Committee

Although several detailed reports on the biological hazards of nuclear weapons testing have been published (1, 2, 3, 4) and the Joint Congressional Committee on Atomic Energy has held two weeks of open hearings on this question (27), there still appears to be some disagreement, even among scientists, in evaluating the hazards. The Radiation Hazards Committee of the Federation of American Scientists has studied the problem and has prepared this report with the desire of assisting in the understanding of the factual background on which any intelligently informed public opinion must be based. A principal purpose of this report is to emphasize that, so far as the magnitude of the hazard is concerned, conclusions which may appear to be in conflict can legitimately be drawn from the available facts.

There does not appear to be much disagreement on the basic quantitative facts with respect to radiation exposures. It is recognized that these are rather wide limits of uncertainty and large areas of ignorance on some important questions. It is also generally recognized that there are, in our civilized environment, other radiation hazards that may be greater than those arising from weapons testing at the present rate. However, a person who feels that the continued testing of large nuclear weapons is valuable to our national security is likely to look at the data in such a way as to suggest that the hazards are "negligible." On the other hand, one who feels that an international agreement to cease testing large weapons, or all weapons, would be a first step toward lessening international tension and distrust, is likely to view the data in such a way as to suggest that the same hazards are "alarming."

It is the conclusion of this Committee that to describe the fallout hazard from nuclear testing as either negligible or alarming is an oversimplification. The Committee believes that the fallout effects deserve moderate weight in decisions concerning continuation or cessation of nuclear tests, although such decisions must be based primarily on other grounds than that of fallout effects.

GENERAL PROPERTIES OF FALLOUT

Nuclear bombs derive their energy either from the fission (or splitting into parts) of the atoms of very heavy elements, or from the fusion of light elements such as heavy hydrogen to form helium. In the case of fission, the atoms into which the heavy atoms of the nuclear explosive are split are called fission products, and almost all of them are radioactive. The fusion reaction is called a thermonuclear reaction, since it takes place only at a very high temperature. So far the only practical way of reaching the temperatures necessary to explode a fusion bomb is by using energy from a fission bomb. Thus nuclear bombs of all kinds, whether fission or fusion, produce approximately the same kinds of hazardous fission products, since even the fusion bomb uses a fission core as an igniting agent. The quantity of fission products produced is directly proportional to the energy derived from fission, whether it is the fission of uranium 233, uranium 235, plutonium 239, or uranium 238. This quantity is relatively small for 'atomic artillery,' larger for bombs such as were used on Hiroshima and Nagasaki, and yet a thousandfold more for a big fission-fusion-fission bomb (the so-called 'dirty' H-bomb) such as was exploded Mar. 1, 1954. On the other hand, that portion of the energy that is derived from nuclear fusion, using materials such as deuterium (heavy hydrogen), leads to a very much smaller amount of dangerously radioactive material for a given energy output. By minimizing the size of the fission core used to ignite the fusion reaction and by omitting the outer fission layer, it is possible to make H-bombs less 'dirty' but never completely 'clean' (except in the rather unlikely event that a fusion reaction can be started by a purely chemical ignition charge).

The distribution of the fallout depends on the size and location of the explosion. Some of the fallout takes place near the site of the explosion within a few hours, some takes place all around the earth in latitudes near that of the explosion within a few weeks, and some is distributed over the entire planet and falls out gradually over a decade or so. Most of the fallout is local for small bombs exploded near the ground, the fraction that is globally distributed increasing both with the size of the bomb and with the altitude at which it explodes. The radioactivity of any given piece of material gradually decreases with the passage of time. The quantity that measures the slowness of this radioactive decay is the half-life: with each succeeding half-life interval, the quantity remaining is halved. The fission products that are globally distributed have time to decay to some extent while they are high in the stratosphere. By the time they fall out, only those of relatively long half-life remain significantly radioactive. Thus, the fission products that constitute a serious hazard in the local fallout are more varied than those in the worldwide fallout. These facts are a basis for possible misunderstanding. When, for example, British Foreign Secretary Selwyn Lloyd said (House of Commons, Feb. 11) that Britain's 1957 tests "will be high air bursts which will not involve a heavy fallout," he presumably meant that the local fallout would not be heavy; the global fallout is actually increased by exploding the bombs at high altitude.

Radioactive materials decay by emitting radiations similar to X-rays, and by ejecting sub-atomic particles at high speed. As they pass through matter, both of these kinds of rays produce ionization, which means that they knock electrons out of molecules. It is the ionization produced in living tissue which is responsible for the biological effects of the radiations. In order to discuss the effects quantitatively, it is necessary to have a unit in which to measure this ionization. Several such units are in use, but we can avoid some unnecessary technical terminology and at the same time make the quantities more directly meaningful, by using as our unit the dose to which the inhabitants of some representative locality have always been exposed. Mankind has always been exposed to a certain amount of natural ionizing radiation: to cosmic rays, to the radioactivity of the rocks of the earth, and to radioactivity in our own bodies. This 'natural

(Report continued on Page 2 and following)

background' radiation, as it is called, varies from one place to another. A typical low natural background is approximately doubled by moving from a wooden house to one of brick or concrete (5), from a region underlain by sediments to one underlain by granite, or from sea level to an altitude of about 13,000 ft. (6). In this report, all radiation doses are expressed in a unit which is the average natural background at sea level (7).

THE EFFECTS OF STRONTIUM 90

The hazard usually recognized as the first to become serious at places far away from the site of the explosion is that resulting from strontium 90 (Sr^{90}). The importance of Sr^{90} arises from the facts that it is one of the more abundant fission products, that it has a long half-life (28 years), and that, being chemically similar to calcium, it is handled very much as is calcium in the metabolic processes of plants and animals. Thus, when it is ingested with our food, it gets deposited along with calcium in bones, where it stays for years, exposing the bones and the bone marrow to the ionization resulting from its radioactive decay. Radiation to the bones can result either in bone cancer or in leukemia, a fatal cancer-like disease of the blood. There is a great mass of clinical data showing that radiation can produce many kinds of cancer (including bone cancer and leukemia), usually after an interim of many years (8). The more radiation, the more likely is cancer, but the experimental data on the actual amount of exposure required to induce cancer in a given fraction of the persons exposed is rather meager.

In the case of leukemia, a recent analysis (18) of the data on patients given X-ray treatment for ankylosing spondylitis, and on persons irradiated in the atomic bombing of Hiroshima and Nagasaki, indicates that in both of these groups, the incidence of leukemia is approximately proportional to the dose of radiation received. The incidence was found to be about one or two individuals per year out of a population of 100,000 for a dose equal to that delivered by natural background over a lifetime of 70 years. The figure is also consistent with the interpretation that 10 to 20% of the normally occurring incidence of leukemia (about 7 per 100,000 per year) is due to natural background radiation, and with the observed increased incidence of leukemia among radiologists and patients given X-ray treatment for enlargement of the thymus.

In the case of bone cancer, about the only quantitative data on human beings comes from 44 adults who were given radium for its presumed therapeutic value three to four decades ago (9). Of the 36 cases having enough radium to give a dose of 100 times the level of natural background radiation or more, 32 had clinically recognizable bone lesions. Only a few of these were malignant (cancer). Among these there was only one single case of bone cancer in which the dose could be determined with any degree of reliability, the others having ingested unknown radioactive mixtures rather than pure radium. This one case had a radium content giving a bone dose of 1000 times background, a dose which was exceeded 3- or 4-fold by three other cases in which cancer has not developed. The growing bones of children may be more susceptible to radiation damage than are those of adults. The very limited amount of data on the effect of radium in adults may be applicable to Sr^{90}, since animal experiments (see note 23) indicate that these two radioactive materials are roughly equal in their cancer producing effect.

In addition to this data on man, there have been some experiments on animals (10, 11) on how the incidence of bone cancer depends on the size of the radiation dose. These experiments make it appear probable, but do not show conclusively, that even extremely small doses increase the incidence of cancer over what it would be without this radiation. Some scientists interpret the results as indicating that the incidence is proportional to the dose (as it is for the genetic effect to be discussed below, and as it appears to be for the cancer-like disease, leukemia). Other scientists believe that there is probably a threshold dose of radiation below which no harm at all is done.

Let us now compare this very limited knowledge of the doses which involve a hazard of producing bone cancer, with the amounts of Sr^{90} received by the population from nuclear explosions. The quantity of Sr^{90} in human bones has been measured both by the US Atomic Energy Commission and by British Atomic Energy Authority observers (14, 15, 16). In late 1955 and early 1956, the average concentration found in about 600 autopsy samples collected from many places throughout the world was such as to give a dose of 1/400 of background; that for children in the northern hemisphere was about .008, and the largest value observed was .2 times background (16).

The concentration of Sr^{90} in human bones is expected to increase, whether further nuclear explosions take place or not, but the quantitative estimation of this increase is subject to many uncertainties. There has not yet been sufficient time or sufficient data accumulated to exhibit clearly the rate at which the Sr^{90} content of bones is coming into equilibrium with the Sr^{90} in the environment. The global fallout of Sr^{90} has, however, been observed (14, 15, 17) in sufficient detail over a time long enough to permit a very rough prediction of the fallout to be expected in the next decade or two. Combining this prediction with experimental data on the calcium content of soils, and on the relative uptake of calcium and strontium in going from soil to plant, from plant to milk, and from plant and milk to man, it has been estimated that, if no further explosions take place, the average concentration of Sr^{90} in human bones will rise, by about 1970, to a maximum which will give a dose of about 1/10th of background (18). If nuclear explosions continue at the rate of about 10 megatons (TNT equivalent) a year, the Sr^{90} concentration will gradually rise to an average, by the year 2000, of about 6 times the level predicted for 1970.

If there is a threshold, it is very important to consider the probable fluctuations of individual concentrations from the average given. Such fluctuations will be produced by variations in the fallout, in the calcium content of the soil, in the dietary habits of individuals, and possibly in other factors. At several places thousands of miles from bomb test sites, a coincidence of rainy weather with the passage of air contaminated by a recent nuclear explosion has resulted in a local fallout of the order of a hundred times the average taken over a large area (19). Nevertheless, the amount of Sr^{90} that has accumulated from all weapons tests up to the end of 1955 does not show as much variation from place to place. As measured, the locally accumulated Sr^{90} varies above and below the worldwide average by a factor which is only about three (20).

The second factor contributing to the fluctuations is the calcium content of the soil. The less calcium there is in the soil of a region, the less the strontium fallout is diluted by natural calcium, so the more strontium will be found in plants growing on that soil. There are regions (for example in Wales) where the calcium content is only 1/40th of the average, so that people living on foods produced from the local soil would build up a Sr^{90} content 40 times the average. An effect of this kind has been confirmed in the analyses of the bones of sheep living on such land (14). Many human beings derive their foodstuffs from a more varied supply only part of which is likely to be so greatly contaminated, but for those who grow a considerable fraction of their own food, the effect will be significant.

Dietary habits also affect the strontium intake in another way. Because of the fact that animals use calcium to a greater extent than strontium in producing milk, the Sr^{90} content of plants is, on the average, about 7 times that of milk. Persons whose eating habits make vegetables the primary source of calcium will, therefore, accumulate about 2 times the average burden of Sr^{90}, since the average was computed for a typical American diet including both milk and vegetables (13, 16, 27).

Since the individual with the largest Sr^{90} burden yet reported was from Vancouver, where other samples were quite normal, it would appear that the fluctuation in this particular case, a factor of 75, is not to be attributed primarily to soil calcium or to fallout fluctuations, but to other random factors possibly including diet. It is expected that this type of fluctuation will decrease markedly as human bones come into equilibrium with the Sr^{90} in their environment (13).

If there is no threshold level for causing leukemia or bone cancer, then one can make rough estimates of the number of death that will result from the fallout, and the fluctuations discussed above will not materially affect this number. The radiation level reached by 1970, if there are no further tests, will cause about

1000 deaths per year throughout the world (estimate based on US statistics and on Lewis' work (18); the level estimated for the year 2000, if the present rate of testing continues, will cause about 5000 deaths per year. These numbers are very uncertain. The true effects may be several times larger or smaller.

The following table is intended to permit comparisons among some of the doses that are relevant to the problem, but the actual numbers must be taken as approximate only. For example, the first two lines depend on the single known case of cancer for which the dose is approximately known. The dose predicted for 1970 is based on tests made through 1956 only. The predicted doses also suffer from uncertainties in the factors by which strontium is discriminated against relative to calcium in the metabolic processes of plants and animals. For example, the Sr^{90} to calcium ratio in human bone compared to that of food has been given as 1/1, 1/8, and 1/2.5 on various occasions within the past year, by qualified scientists (22, 16, 13). One complicating factor is that this "discrimination ratio" depends on the particular food.

TABLE 1

Bone Doses Relative to Natural Background (23)

Cancer in 25 per cent of 4 adult cases	3000.	(9)
Minimum clearly associated with bone cancer	1000.	(9)
Bone lesions in 100% of 20 adult cases	300.	(9)
Bone lesions in 75% of 16 adult cases	100. to 300.	(9)
Estimated dose to increase leukemia incidence by 10%	1.0	(18)
Occupational maximum permissible concentration Sr^{90}	20.	(24)
"Maximum permissible concentration" for population	2.	(24)
Natural background (ranges from .7 to 4.)	1.	(25)
Additional radiation from living in a brick house	.2	(13)
Additional radiation from living at high altitude (5000 feet above sea level)	.15	(13)
Average 1955 measurements on human bones, Sr^{90}	.0025	(16)
Average dose in 1970 if no more tests, Sr^{90}	.07	(13)
Average dose in 2000 if tests continue, Sr^{90}	.4	(26)

So far, we have tried to present the essential quantitative data on which there is not too much disagreement, and on which conclusion relative to the hazard of bomb testing must be based. Let us now state the conclusion in 2 different ways, both correct, yet differing in emphasis:

CONCLUSION 1 Even if nuclear weapons testing continues at the present rate (taken to be about 10 megatons, TNT equivalent of fission energy per year), the worldwide average of the bone dose to a human being as a result of the Sr^{90} he contains will probably rise to a level of about half that of the natural background, namely to a level which is about one two-thousandth of the smallest dose known to have been associated with a case of bone cancer, and is about the dose that the walls of an ordinary brick house give to its inhabitants.

CONCLUSION 2 There seems reason to believe that even small doses of radiation can produce leukemia and bone cancer, and that natural background radiation is responsible for a certain fraction of the "normally" occurring incidence of these effects. Any increase in radiation received by large numbers of people should, therefore, be avoided if possible. Those who derive their calcium from vegetables grown in soil of low calcium content would receive by 1970, from weapons already detonated, a dose several times background. If other fluctuations happened to coincide with this one, the dose could be further increased by quite a large factor.

Both conclusions are a bit extreme, yet both are correctly derived from the quantitative data before us. One of them neglects the fact that local variations from the average exist, and seems to suggest that a small dose is a safe dose which will produce no effect. The other emphasizes the possibility that even small doses may affect a considerable number of individuals, and neglects the fact that, if extreme local variations do exceed reasonable limits, it will be possible to add calcium fertilizers to the soil, or to stop using certain limited areas for the production of milk or of other foods rich in calcium. If we take local variations into account, it is still possible to draw correct, yet widely differing, conclusions:

CONCLUSION 1 Since the data suggest that no more than a few percent of the population will receive Sr^{90} concentrations more than 10 times the mean, and since these fluctuations will probably decrease as equilibrium is approached, only a small fraction of the population will receive, as a result of bomb testing continued at the present rate, a dose larger than about four times background, a dose which corresponds to only 1% of the smallest dose known to have been associated with a case of bone cancer.

CONCLUSION 2 If the cancer-producing effect is proportional to the dose, as it may be, the average exposure of about 1/10th of background that will result from all tests conducted up through 1956 may be expected to result in leukemia or bone cancer in 60,000 persons (27).

GENETIC EFFECTS

The second hazard to be considered is that of genetic damage as a result of mutations produced by the exposure of the gonads to ionizing radiation. Here the qualitative facts are better known and more readily agreed on than in the case of the cancer-producing properties of Sr^{90}.

Mutations are changes in the genes, the units determining the hereditary characteristics passed on from a parent to his child. Mutations are the main source of the variability out of which natural selection is able to produce evolutionary change. However, although mutations can be beneficial, leading geneticists are agreed that almost all mutations in humans are harmful. Some are lethal -- the offspring bearing the changed gene dies before or soon after birth as a result. Some are more mildly deleterious. Some are completely recessive so that they have no observable effect at all on the individual, and it is only when two such genes are combined, usually a number of generations later, that their harmful effect is felt. Mutations occur spontaneously as a result of natural ionizing radiation and of chemical processes in the body. The mutations produced by man-made radiation sources are of exactly the same kinds. Hence, when a mutation occurs, there is no possible way of determining whether that particular case was spontaneous, or resulted from medical X-rays, or from nuclear bomb tests. There is no amount of radiation that is too small to have an effect. The number of additional mutations will be proportional to the total dose of radiation received by the gonads up to the time that the offspring is conceived, whether the radiation is received in a single large dose or in many small doses spread over many years. Since the average childbearing age is about 30 years, gonad doses are given in this report in terms of a 30-year exposure to average natural background (7).

Most of the reports on the subject emphasize the fact that any exposure to ionizing radiation is harmful, no matter how little. But it is a fact that the human race has always been exposed to radiation, that individuals subject to different living conditions (different altitude, different house materials) receive quite different amounts of radiation, and that medical use of X-rays has increased the amount of radiation we receive. It is necessary to attempt some quantitative evaluation of the hazards involved in any given dose level. Here, the data available are even less satisfactory than in the case of the bone cancer hazard. The amount of radiation it takes to increase a mutation rate by a specified amount could be determined if it were known what fraction of the natural mutation rate is produced by natural radiation. But this is not known, and animal experiments are not directly applicable to human beings. Mutations are so rare statistically that a large number of cases would be needed to give us the data. Studies of the children born to the population irradiated in the bombing of Hiroshima and Nagasaki have failed to give definite information on this point (28). We can, however, say that a dose equal to background certainly will no more than double the natural mutation rate; it has been estimated that it probably increases it by at least 1 to 2% (29).

There is another point at which the quantitative evaluation of the genetic hazard becomes difficult. There is a wide difference of opinion among geneticists on what the effects of even a known increase in the mutation rate would be. The report of the British Medical Research Council (2) goes into considerable detail in considering the social load of caring for cases of disease that would result from a doubling of human mutation rates if continued for many generations. Other geneticists, including Nobel laureate H. J. Muller, believe that such a large increase would be catastrophic. The Genetics Committee of the National Academy of Sciences points out that there is a dose of radiation, its magnitude unknown, at which birth and death rates would be so altered that the population would decline to extinction. However, the fact that some human populations have carried on at high altitudes in the Andes, where the background is 3 times the average, indicates that a dose of that magnitude is not catastrophic.

The natural background of radiation to which we are all exposed results in a dose which depends on where an individual lives (6). The high backgrounds are found only in rather limited areas at high altitude (where less of the cosmic radiation is absorbed by the earth's atmosphere) or in areas where the rocks of the earth are a good deal above average in their radioactivity.

In spite of the large uncertainties involved, it is important to look at whatever quantitative estimates of the genetic hazard are available. Mutant genes have ultimately to be eliminated from the population, and, on the average, this can occur only through the premature death of an individual, or through the operation of the mutation in such a way as to prevent an individual from having children (30). Six geneticists on the NAS committee estimated (31) the number of mutant genes that would be produced by a given dose, and passed on to the next generation. They agree on a best estimate of about 1 gene per 50 of population per background unit, and believe the true number is between 1/10 and 10 times this value. For example, a dose of .003 30-year background units to the population of the world over one generation would produce between 10,000 and 1,000,000 mutations, most of which would appear many generations after the irradiation. (It is only the total dose which matters in regard to genetic effect; thus, a dose of .003 30-year background units would have the same genetic effect, for example, whether received with a dose rate .003 times background rate for a total of 30 years or with a dose rate 0.9 times background rate for 1/10 year.) J. B. S. Haldane estimates (32) that the same dose would cause between 2,000 and 300,000 deaths, in good agreement with the members of the American committee.

Let us now consider the dose of radiation to which our gonads are exposed as a result of nuclear weapons testing. Here, again, the quantitative information is characterized by a rather wide range of uncertainty. Nuclear explosions which have already occurred have exposed persons to doses which vary from very little for persons who live in solid houses in arid regions of the southern hemisphere, to a dose equal to the 30-year average natural background for a small community near the Nevada test site (33), 44 such background units for the inhabitants of Rongelap Island (34), and even more for the fishermen of the Fortunate Dragon No. 5 (35). The average fallout exposure for the inhabitants of the US from tests to 1955 is estimated by G. M. Dunning (36) of the US Atomic Energy Commission to be .02 background units. For residents of the United Kingdom, the Medical Research Council (37) finds the dose accumulated in 30 years from weapons already detonated (1956) will be .0003 to .0005 background units. If weapons testing continues at the present rate, the average doses are estimated by the AEC for the US as between .005 and .1 background unit in 30 years (39). The wide limits of uncertainty and the inconsistencies in these figures reflect the uncertainties in the amount of fallout that is removed from the surface of the ground by weathering, in the amount of protection afforded by buildings, and in the computation of the dose from the daily fallout measurements (the gamma-ray doses cannot be measured directly because they are much smaller than the normal background (17).

TABLE 2

Gonad Doses Relative to 30-Year Average Background (4 rad)(7)

To increase mutation rate 5 per cent (estimates range from .05 to 3.)	1.	(29)
Natural background (varies from .5 to 4.)	1.	(6, 25)
Additional dose from living in a stone house	.2	(13)
Additional dose from living at high alt. (5000 ft.)	.15	(13)
Occupational "tolerance"	12.	(40)
"Tolerance" for population	2.	(41)
Average from bombs exploded up to 1955	.003	(32)
Average if testing continues (estimates range from .005 to .1)	.03	(38)
Population average from diagnostic X-rays	1.	(42)
Dose to an individual from a fluoroscopic examination (gonad dose)	.5	(42)
Luminous dial wrist watch, 15 years only (1 ft. from gonads)	.2	(6)

It is obvious that, with the wide limits of uncertainty in the dose being reached, in the effect of a given dose on the mutation rate, and in the genetic damage and death rate that would result from a given increase in the mutation rate, one could state extreme conclusions by simply selecting optimistic or pessimistic estimates of each of the factors involved. However, it is possible to give clearly contrasted conclusions even using a single estimate of the dose -- say, .003 unit for a worldwide average from bombs already exploded, and 10 times that in 30 years if testing continues at the present rate:

CONCLUSION 1 Even if nuclear weapons testing is continued at the present rate, it will produce on the average an amount of radiation exposure only about 1/30th that of the unavoidable natural background, the same increase that would result (from cosmic radiation) on moving one's home from sea level of an elevation of 1000 feet.

CONCLUSION 2 Weapons already exploded will result in at least thousands of human deaths -- more likely tens of thousands, and maybe hundreds of thousands.

Here, although the conclusions seem very different, neither is extreme or overdrawn. The first emphasizes the smallness of the relative increase; the second emphasizes the large number of individuals affected.

OTHER HAZARDS

In regard to worldwide effects of fallout from nuclear tests, it appears at present that the genetic effects and the effects of Sr^{90} are the principal ones, and that no other fallout effects present a comparable hazard, although there is not yet sufficient data to say with absolute certainty that this is so.

In addition to these effects, associated with relatively small radiation doses to the individual, other hazards, appearing at higher radiation levels, deserve brief mention (27). Exposure of the whole body to about 100 30-year units in a short time can result in radiation sickness. Exposure to about 120 units can result in a shortened life span, and is likely to be fatal in about half the cases. Temporary sterility is produced in about half the cases exposed to 30 units. Eighty-five cases of partial cataract occurred among the 1250 survivors closest to the Hiroshima bomb. Eating or breathing of fission products also involves other hazards which, at great distances from the bomb, show up only after the Sr^{90} hazard is already serious. Marine organisms are able to concentrate many thousandfold certain radioactive elements that may be dissolved in the ocean (44). This can become a hazard to the organisms themselves, or to those who eat them. There has not yet been time to explore thoroughly all possible hazards of this kind.

As an example of what may show up in the complex biological processes of life on earth, we mention a particular case that was unsuspected until 1957, about 3 years after the explosion that presumably furnished the raw material. Clams collected at Rongelap, the island which received the largest fallout dose from the explosion of March 1, 1954, have been found to contain cobalt 60 (45), an isotope which was not detected in careful analyses of the fallout ash or of the ocean water. Starting from an extremely dilute solution, the clams, or some organisms on which they feed, have concentrated this radioactive isotope to a level which is easily measureable, presumably in the form of vitamin B_{12}, which is even more abundant in clams than in liver (46), and which has a cobalt core. The biological harmfulness of this resultant level, to the clams or to humans who eat the clams, has not yet been evaluated.

So far this discussion has not made use of the term MPC or "maximum permissible concentration" of a radioisotope, or the term "tolerance dose" of radiation. These terms have not been used for two principal reasons. First, reference to an MPC is not essential to an understanding of the relation of the hazard to the dose received. Second, and much more important, the term "permissible" dose is a misnomer when applied to the problem of fallout radiation. This term is generally understood to mean either a "safe" level, which will produce no deleterious effect whatsoever, or else a level which is acceptable by those exposed, or their authorized representatives, on the basis that any deleterious effects incurred are sufficiently compensated for by advantages received.

In the case of fallout radiation, there is no safe level. There is complete agreement among geneticists that genetic effects can be produced even by very small doses of radiation; as for effects of Sr^{90}, many qualified specialists believe these also can be produced even by small doses.

If there is no safe dose of radiation, then the term "permissible" dose should be used only in the second sense given above -- a dose level at which the deleterious effects are acceptable to the exposed persons, in return for compensating advantages. For example, when a physician gives an X-ray to a patient, the physician is making a decision that the benefits outweigh the deleterious effects. In the present state of international concern about fallout radiation, it does not seem that the involuntarily exposed peoples outside of the testing countries would be unanimously agreed that the advantages they receive from nuclear testing sufficiently compensate for the disadvantages of the effects known to be produced by the radiation, even though the effects of fallout radiation may be small compared to other normally occurring, similar effects.

Although this report deals primarily with the hazards of testing nuclear weapons, it is important at least to mention some other related hazards. Whether fission energy is used in bomb testing, in war, or in the peaceful production of useful power, the same quantity of fission products is formed per unit of fission energy. The bombs used in tests are obviously a small fraction of what would be used in an all-out war, and the worldwide fallout will go along in proportion. In testimony before Congressional committees, it has been stated that full-scale nuclear war would result in hundreds of millions of deaths from fallout radiation, in addition to other hundreds of millions from blast, fire, and direct radiation (27, 47).

In the case of nuclear power plants, the fission products are produced as a waste product in the necessary chemical reprocessing of the fuel. However, the quantity that will probably be produced is so tremendous that present knowledge is inadequate to plan for its disposal. This is why the members of the NAS Oceanography committee "plead with all urgency for immediate intensification and redirection of scientific effort on a worldwide basis towards building the structure of understanding that will be necessary in the future. This structure cannot be completed in a few years; decades of effort will be necessary and mankind will be fortunate if the required knowledge is available at the time when the practical engineering problems have to be faced" (48). This particular hazard will be nearly eliminated if and when thermonuclear power (that derived from nuclear fusion) is ever developed to the point that it replaces fission power plants.

Another related hazard to which very considerable attention has been directed, mainly as a result of concern about nuclear bombs, is that of the medical use of X-rays in diagnosis and therapy. Even a luminous dial wrist watch can expose its wearer to significant amounts of radiation, comparable with the natural background (see tables 1 & 2). In connection with their report on the effects of atomic radiation, the Genectics committee of the National Academy of Sciences has recommended "that the medical authorities of this country initiate a vigorous movement to reduce the radiation exposure from X-rays to the lowest limit consistent with medical necessity; and in particular, that they take steps to assure that proper safeguards always be taken to minimize the radiation dose to the reproductive cells" (49). The new awareness of the deleterious effects of radiation is leading to greatly improved techniques in the use of X-rays, and by these improvements it will be possible to reduce the radiation doses received to levels that are justifiable in the light of the great benefits obtained.

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7. This average background level is taken as .15 rad (a unit of radiation dose) per year to the bone, and 4 rad in 30 years to the gonads (6, 25). The bone dose is larger by .02 rad per year because of the radium normally present in the bones.

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9. W. B. Looney et al, "A Clinical Investigation of the Chronic Effects of Radium Salts Administered Therapeutically (1915-1931)," Amer. J. Roentgenol. 73, 1006-1037 (1955).

10. W. V. Mayneord and J. S. Mitchell, "An Attempt to Estimate the Hazard from the Ingestion of Strontium 90," ref 2, p 126.

11. M. P. Finkel, M. Lisco, and A. M. Brues, "Toxicity of Strontium 89 in Mice. Malignant Bone Tumors," in Argonne National Lab Report No. 5378, pp 106-117 (1955).

12. H. Auerbach, "Geographic Differences in Bone Tumor Death Rates," Argonne National Lab Report No. 5426, p 9 (1955).

The FAS is a national organization of scientists and engineers concerned with the impact of science on national and world affairs. This issue of the Newsletter contains a report prepared by the FAS Committee on Radiation Hazards, which is located in Philadelphia. Fallout hazards are the subject of considerable attention, and it is important that the public be informed about the extent of these hazards. The FAS Washington Office is therefore publishing this report in its entirety. Additional copies are available from the FAS Washington Office at 10¢ each, 15 for $1, and $5 a hundred.

Membership of the FAS Committee on Radiation Hazards: Walter Selove (Assoc. Prof. Physics, U. Pa.), Chairman; Norman Goldberg (Asst. Prof. Phys., U. Pa.), Vice-chairman; R. Burling (Lect. Phys., U. Pa.), S. C. Glauser (Res. Fellow, biophys., U. Pa.), D. L. Glusker (Res. Chemist, Rohm & Haas Co.), P. Grant (Res. Assoc., Inst. Cancer Res.), R. C. Hoyt (Assoc. Prof. Phys., Bryn Mawr College), J. R. Pruett (Asso. Prof. Phys., Bryn Mawr College).

13. W. F. Libby, "Radioactive Fallout," American Physical Society meeting, Washington, D.C., April 26, 1957.

14. W. F. Libby, "Radioactive Strontium Fallout," Proc. Nat. Acad. Sci. 42, 365-390 (1956).

15. W. G. Marley, "The Long-range Fallout from Nuclear Test Explosions," ref 2, p 121.

16. J. L. Kulp, W. R. Eckelman, and A. R. Schulert, "Sr^{90} in Man," Science 125, 219-225 (1957).

17. M. Eisenbud and J. Harley, Science 124, 251 (1956).

18. E. B. Lewis, "Leukemia and Ionizing Radiation," Science 125, 965-972 (1957).

19. In the spring of 1953, Troy, N.Y. received an unusually heavy rainout giving .4 mr/hr (20), whereas the average for the US after this series of tests was .003 mr/hr (21).

20. H. M. Clark, Science 119, 619 (1954).

21. M. Eisenbud and J. Harley, Science 121, 677 (1955).

22. M. Eisenbud, "Global Distribution of Radioactivity from Nuclear Detonations, with special reference to strontium 90," Washington Academy of Sciences Fall Symposium, Nov. 15, 1956.

23. The background used as a unit here is .15 rad per year (see note 7). Radioisotope burdens were converted to rad per year using these data: for Ra, 1μc/kg Ca gives 40 rad per year, and for strontium 90, 1μc/kg Ca gives 3 rad per year (Ref. 1c pp II-9 and -13). M. P. Finkel, "Relative Effects on Survival and Tumor Incidence of some Internal Emitters," in Argonne National Lab Report No. 5518, pp 105-112 (1956), reports that the carcinogenic effect of a rad from Ra is roughly the same as that of a rad from strontium 90.

24. Recommendations of the International Commission on Radiological Protection, British J. Radiology, Supp. 6, pp 1-92 (1955).

25. Ref. 1c, Report of the Subcommittee on Toxicity of Internal Emitters, p 13.

26. The doses for continued weapons testing are based on the arbitrary assumption that the rate of release of fission energy will be about 10 megatons TNT equivalent per year, which is roughly the average for the past few years.

27. Hearings on Radioactive Fallout and its Effects on Man, Joint Committee on Atomic Energy, US Congress, May 27-June 7, 1957.

28. Ref. 2, p 44.

29. Ref. 1 b, p 24.

30. Ref. 1 b, p 26.

31. Ref. 1 b, p 27.

32. J. B.S. Haldane, Nature 176, 115 (1955); and Nature 177, 227 (1956).

33. G. M. Dunning, "Protecting the Public during Weapons Testing at the Nevada Test Site," J. Amer. Medical Assoc. 158, 900 (1955).

34. "A Navy Medical Team Studies Fallout Effects," Bulletin of the Atomic Scientists 12, 58 (1956).

35. T. Shiokawa et al, "Investigations of the Radioactive Contamination of the No. 5 Fukuryu Maru," in ref. 4.

36. G. M. Dunning, "Effects of Nuclear Weapons Testing," Scientific Monthly 81, 265-270 (1955).

37. Ref. 2, p 56.

38. Ref. 1 b, p 22.

39. Ref. 2, p 57.

40. Ref. 1 b, p 29.

41. The NAS Genetics Committee (ref. 1 b, p 29) sets 10 rad/30 years as the upper limit for the population; the Medical Research Council (ref. 2, p 64) refuses to set such a limit, but says that it is unlikely that any authoritative recommendation will name a figure larger than 6 rad/30 years.

42. S. H. Clark, "Genetic Radiation Exposures in the Field of Medicine," Bulletin of the Atomic Scientists 12, 14-18 (1956).

43. F. Buschke and H. M. Parker, "Possible Hazards of Repeated Fluoroscopies in Infants," J. Pediatrics 21, 524-533 (1942).

44. Ref. 1 b, p 77.

45. H. V. Weiss and W. H. Shipman, "Biological Concentration by Killer Clams of Cobalt 60 from Radioactive Fallout," Science 125, 695 (1957).

46. B. E. Proctor and D. A. Lang, "Vitamin B_{12} Content of Soft- and Hard-Shell Clams," Nature 168, 36 (1951).

47. Testimony of Lt. Gen. James M. Gavin, Army Chief of Research, before Senate Subcommittee on the Air Force, May 25, 1956.

48. Quoted from the recommendations of the National Academy of Sciences Committee on the Effects of Atomic Radiation on Oceanography and Fisheries, ref. 1 b, p 83. Also in Science 124, 13 (1956).

49. Quoted from the recommendations of the National Academy of Sciences Committee on Genetic Effects of Atomic Radiation, ref. 1 b, p 28 (1956).

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