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Effects of radiation and fallout

James F. Crow

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BY JAMES F. CROW

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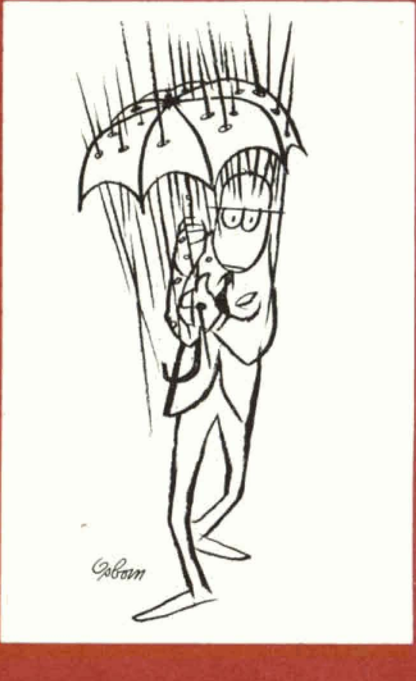

is some descendant of mine – a promising grandson or granddaughter – going to die of leukemia or bone cancer at 20 even though I know today the danger from nuclear fallout? A reasonable amount of intelligence and social concern on the part of the generation of living adults now *can* prevent this from happening.

But failure to produce this "ounce of prevention" has other and equally fatal consequences. Insensitiveness to the anxious concerns of smaller nations who have suffered deeply from direct hits, as well as fallout (witness Japan), can and has produced festering international hatreds which erupt into international catastrophes. An example was our "Japanese Exclusion Act" of 1924 and its natural follow-up – Pearl Harbor in 1941.

This pamphlet is a vivid warning. It can, as I see it, lead to one conclusion only. That is this: to continue to carry out nuclear bomb tests risks life, now and for future generations. One hopes that the voice of a concerned public may make itself felt.

Executive Secretary Emeritus
American Friends Service Committee

the public affairs committee

This pamphlet is one of a series published by the Public Affairs Committee, a nonprofit educational organization founded in 1935 "to develop new techniques to educate the American public on vital economic and social problems and to issue concise and interesting pamphlets dealing with such problems, derived wherever possible from the long-time studies of leading research institutions."

EFFECTS OF RADIATION AND FALLOUT

BY JAMES F. CROW

Dr. James F. Crow, Professor of Genetics at the University of Wisconsin, was a member of the committee on the genetic effects of radiation of the National Academy of Sciences – National Research Council. He was also among the authorities who testified at the Hearings of the Joint Congressional Committee on Atomic Energy in June 1957.

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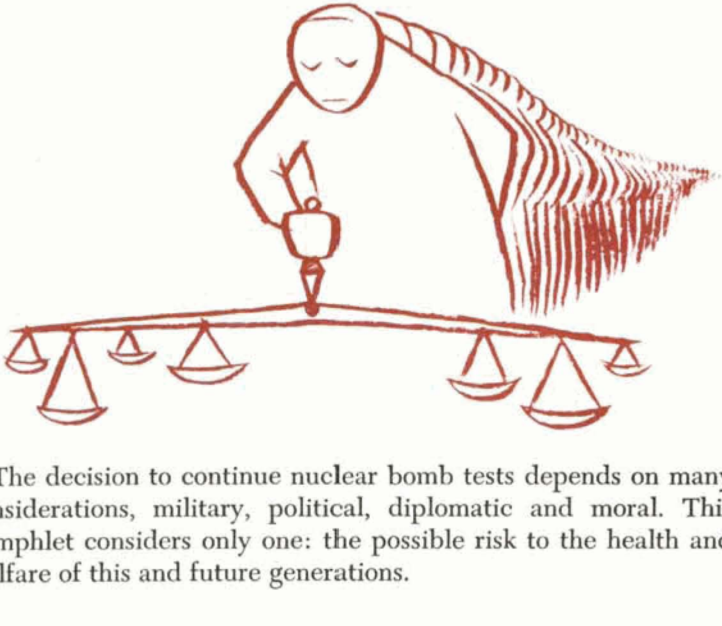
The atomic age has brought great hopes and even greater fears – hopes for economic advance through a new source of energy and for scientific and medical discoveries from radioactive chemical tracers, but, at the same time, fears of an unspeakably horrible nuclear war.

But regardless of the final good or bad from fusions and fissions, we are faced with an immediate problem – radiation. For radiation is an inevitable product of nuclear energy, whether used as a controlled power source or for producing an explosion. In industrial applications, protecting workers from these radiations and getting rid of radioactive wastes are troublesome and expensive problems. In bomb tests, radiations and radiation-producing products are given off, some of which are carried over the entire surface of the earth. When these descend as "fallout" everybody is exposed one way or another.

Is the harm from fallout negligible, as some have said? Or is it so dangerous that it constitutes, in itself, a sufficient reason to stop further testing? How does it compare with other risks that we grudgingly, and often willingly, accept – such things as automobile and airplane accidents, possible risks from cigarette smoking, air pollution by smoke, chemical wastes, and automobile exhausts? How does the risk compare with that from other sources of radiation – natural radiation and medical X-rays? These are vital questions.



The decision to continue nuclear bomb tests depends on many considerations, military, political, diplomatic and moral. This pamphlet considers only one: the possible risk to the health and welfare of this and future generations.

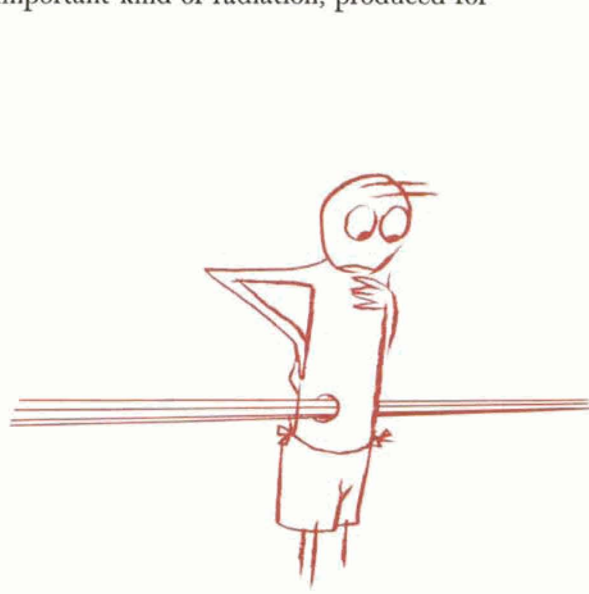
RADIATION

WHAT is radiation? We cannot see, hear, smell, taste or feel it. Yet it can have the most devastating effects on the body. Enough radiation is fatal; smaller amounts may cause burns or loss of hair. There are long-delayed effects, too, such as life shortening and cancer. Still more insidiously, radiation may produce changes in heredity causing abnormalities or disease which may occur many generations later.

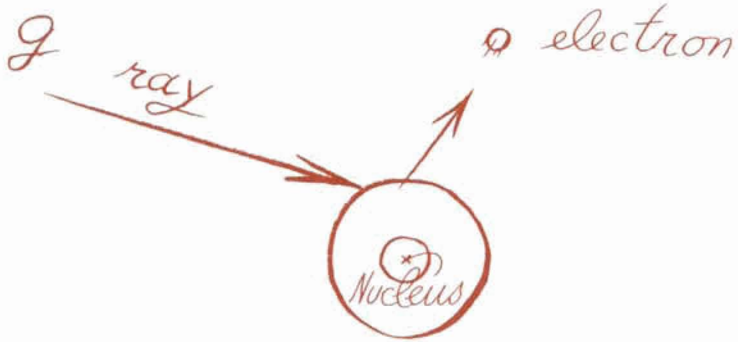
Radioactive chemicals are those whose atoms have a tendency to disintegrate. This may be occurring naturally, as in radium or uranium, or as a consequence of nuclear fission, in strontium-90 and cesium-137 – two elements recently brought from obscurity to notoriety.

Different radioactive elements disintegrate at different rates. For example, strontium-90 decays at such a rate that half of the atoms have disintegrated in about 28 years; thus it is said to have a half-life of 28 years. Elements vary in their half-lives from milliseconds to millennia.

When a radioactive atom disintegrates it gives off several kinds of *radiations*. One very important kind of radiation, produced for example when cesium-137 disintegrates, is *gamma* radiation. Gamma rays are very much like ordinary light except that they have more energy and can penetrate objects that we usually regard as opaque. They go through human tissue much as ordinary light goes through glass.



The characteristic feature of all radiations is that they carry energy from one point to another. Radiation has been aptly described as "energy on the move." In fact, it is moving at a rate of some 186,000 miles per second! It is this packet of absorbed energy that leads to all the manifestations of radiation that we detect.



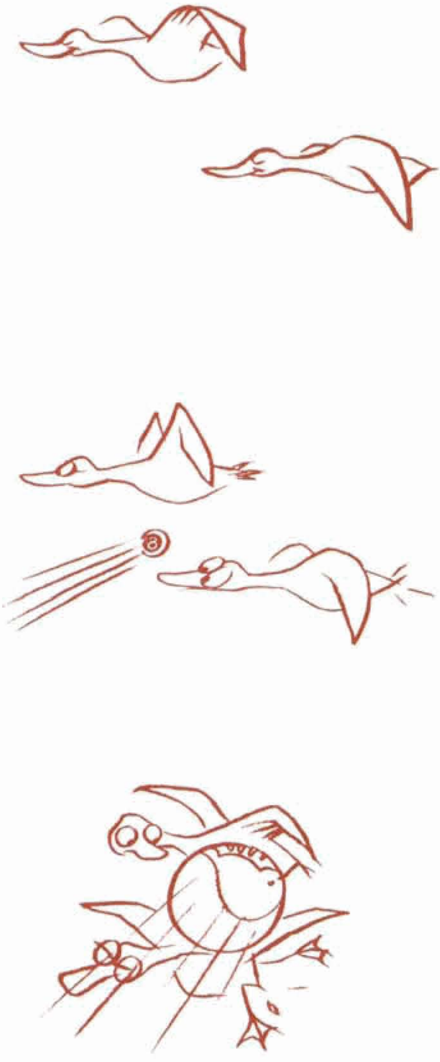
how do radiations affect the body?

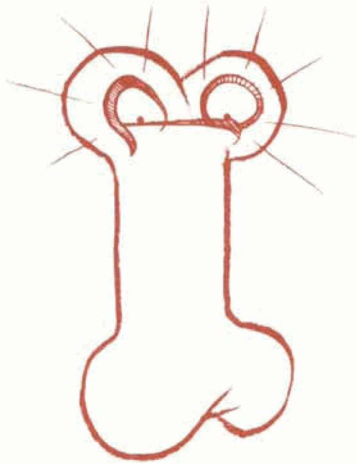
An atom is composed of a central core surrounded by widely separated electrons. A gamma ray, when it encounters an atom, causes an electron to be dislodged and sent into space. The electron, in turn, usually attaches to another atom. This process of electron removal and reattachment is called *ionization*. The original gamma ray usually goes on giving rise to other ionizations until its energy is spent, thus producing a cluster of ionizations. It is the ionization process, and the variety of chemical events which ensue, that causes the various biological effects such as killed cells, cancer, or altered heredity.

Very similar to gamma rays are ordinary X-rays, though gamma rays are somewhat more penetrating. The familiar X-ray picture depends on the ability of X-rays to pass through body tissue. But, of course, there cannot be 100 per cent passage or there would be no picture. Since fewer rays pass through the bone than through the soft parts, the bone shows up as a less exposed part on the film.

One might think of the human body as something like a huge, very dense flock of small birds, the individual birds corresponding to atoms in the body. A bullet shot into the flock would very likely pass all the way through, but, if it struck a bird, that bird might be at any position. A billiard ball would be less likely to go through without hitting any of the birds, and fewer balls would emerge on the other side of the flock without having caused any injury. A balloon or basketball would strike a bird very near the edge of the flock and would hardly get into the interior at all. The bullet, billiard ball, and balloon correspond to a gamma, X- and light ray.

Some radioactive elements and nuclear fission may also emit, besides gamma rays, tiny particles of high speed (although slower than gamma and X-rays). From the standpoint of radiation damage, the important ones among these are *beta* particles (the same as electrons) and *neutrons*. They have the same biological effect as gamma and X-rays for they, too, produce ionizations. The word "radiation" includes





these particles as well as rays.

Beta radiation differs from gamma in being much less penetrating – only a millimeter or so in body tissue. Thus beta radiation from an external source affects mainly the skin. But it can affect the internal parts in another way. For example, strontium-90, which emits beta particles, gets into the body in the food, thence to the blood stream and finally the bone, where it remains, giving off beta radiation to the bone for many years.

Neutrons are highly penetrating, comparable in this respect to gamma rays. They will not be discussed further here, however, for although important near the explosion, they are not a significant factor in distant fallout.

how is radiation measured?

The harm from any type of high energy radiation results from ionizations in the body tissue. This means that all the various kinds of radiations can be compared on a common biological scale by measuring the ionizations produced.

The conventional unit is the *roentgen,* or *r,* named after Wilhelm K. Roentgen, the German physicist who discovered X-rays. The official definition of a roentgen is a technical one, but in human tissue a roentgen is about 2 ionizations per cubic micron, a micron being 1/25,000 of an inch. Thus one *r* over the whole body, which we often regard as a small amount of radiation, may produce some 10^{17} ionizations – that is – 1 followed by 17 zeros. Yet the atoms that are ionized are only an infinitesimal fraction of all the atoms in the body.

fallout

A nuclear explosion emits enormous amounts of radiation and radioactive products, but most are dissipated within a short distance. (With H bombs, a few dozen miles is a short distance!) In peacetime testing, personnel are, of course, protected from any such near effects. Our concern in this pamphlet is with distant fallout.

Even "small" explosions in the *kiloton* range, that is – equivalent to thousands of tons of TNT – send appreciable amounts of material into the upper atmosphere. Here the winds are prevailingly eastward and of such a speed that the radioactive particles are carried around the world in four to seven weeks. Most of the particles fall down, perhaps carried by rain or snow, in a few days or weeks, so most of the fallout is concentrated in roughly the same latitude as the explosion.

Because of the easterly direction of the winds, the heaviest fallout is east of the test site. For example, fallout from the Nevada tests is heaviest in measuring stations east of the tests. Regions to the west are affected principally by particles that have been around the world.

On the other hand, explosions in the "big" *megaton* range – equivalent to millions of tons of TNT – send radioactive debris to much greater heights. Here in the stratosphere, above the clouds and rain, the fine radioactive particles – a thousandth or ten-thousandth of an inch or less in diameter – remain up for astonishingly long periods of time. The half-time, i.e. the time when 50 per cent have come down, is about a decade.

During the time that it is in the upper air the material has time to become widely distributed over the whole globe. Thus fallout reaches all parts of the earth, though there may be local differences in amount. These differences depend mainly on latitude and on local weather conditions, for it is likely that much of the fallout that reaches the earth's surface is brought down by rain and snowfall.

Since the particles remain in the upper air so long, most of the radiation from elements with a short radioactive half-life is, fortunately, dissipated harmlessly far above any human activity. Only those that disintegrate slowly will remain in appreciable amounts by the time the fallout reaches the earth. The two principal elements with a combination of long (but not too long) half-life and a tendency to penetrate and remain in the human body are strontium-90 and cesium-137.

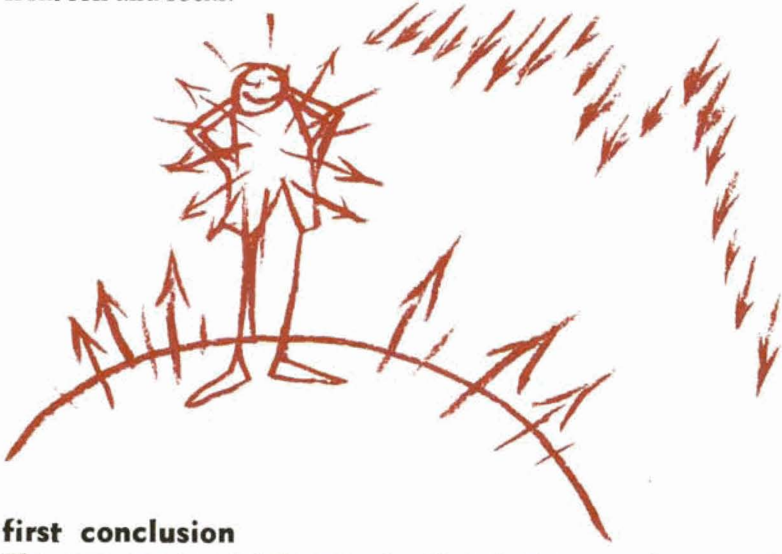
Fallout affects humans either directly – through penetrating radiations from outside the body – or indirectly – by being present in the food we eat or the air we breathe, and thus being carried to the body interior.

Now that we realize that everyone encounters some fallout, the important question becomes: How much? Is the amount large enough to have any significance? Is there enough strontium-90 in milk and cheese to be a health hazard? Are our descendants seriously endangered?

natural radiation

It must be emphasized that radiation is not something new in man's biological experience, resulting from his discovery of X-rays and nuclear energy. There are natural radiations which have been with us all along. These natural, background radiations come from naturally radioactive materials in the soil, radioactive chemicals in the body, and cosmic rays from outer space.

The average person in America receives some 0.1 roentgen or more per year. The amount varies somewhat with altitude, for cosmic rays increase by about 50 per cent in going from sea level to a mile high altitude. Likewise, different soils and rocks differ in radioactive content. But, roughly, we get about a quarter of the amount from cosmic rays, a little less than this form radioactive elements (mainly potassium) in the body, and about half from soil and rocks.



first conclusion

The present rate of fallout in the United States, as determined by "Project Sunshine" of the Atomic Energy Commission (AEC), is such as to give an external dose rate of from 0.001 to 0.005 roentgens per year. Independent data from Great Britain agree closely. Thus radiation from fallout is only a small fraction, less than 5 per cent, of what we receive as natural radiation. Furthermore, the kinds of radiation from natural sources have about the same biological effects as fallout.

This permits a first conclusion. *Any injury due to fallout must be a small fraction of that which is already occurring due to* *natural radiations.* This puts the fallout problem in some sort of perspective. The effects of fallout may be expected to be nothing new, but only a statistical increase in other radiation effects, whatever these are. If natural radiations are harmful, so is the present rate of fallout, but to a lesser extent because of its lesser amount.

Let us now examine the biological effects of radiation.

GENETIC EFFECTS

IT IS convenient for discussion to divide the biological effects of radiation into two kinds:

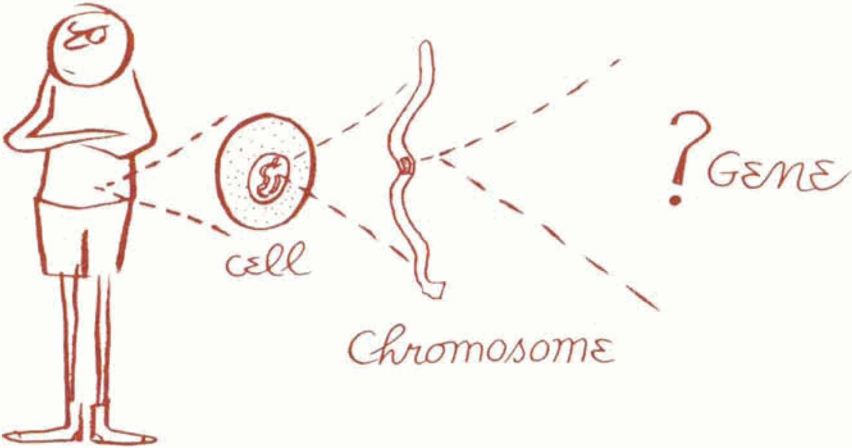
1) *genetic* damage, or effects showing up in future generations;
2) *somatic* damage, or effects showing up later in the life of the irradiated individual.

chromosomes, genes, and mutations

A human adult has some hundred million million cells. (Needless to say, nobody has ever counted them.) Inside the cell is a nucleus containing threadlike or wormlike *chromosomes.* There is some uncertainty about the exact number per cell; some investigators have reported 48, others 46.

Each chromosome has many (perhaps a few hundred) genes, arranged single file along the chromosomes. Nobody knows what a gene is, although there is some knowledge of the chemical makeup of the chromosome. We do know that associated with a particular site on the chromosome is the determiner of a specific hereditary factor, and this we call the gene. The collection of genes that we inherited from our parents determines what we are. Each gene carries out its particular function, often in complex interworking relations with others and with the environment.

Chromosomes, and therefore genes, occur in pairs, one member of each pair having come from each parent. Just before the egg or sperm is produced there is a randomization process by



which each egg or sperm receives one, and only one, member of each pair (for this process biologists use the word *meiosis,* meaning "to make smaller.") Our entire biological legacy passes through these two tiny cells – the egg no larger than a dot on this page, the sperm much smaller, so that a microscope is needed to see it.

A gene is remarkably stable. Ordinarily it is transmitted unchanged from parent to offspring for generation after generation. But rarely, perhaps once in a hundred thousand generations, a gene changes, or *mutates.* The changed, or *mutant* gene is just as stable as the original, and it, too, is transmitted generation after generation until, on the average some hundred thousand generations later, it mutates again, either back to the original or to a third form.

Although, as just seen, the likelihood of any particular gene mutating in any particular generation is very small, on the other hand, there are a great many genes in the cell (perhaps 20,000) so the probability of some one of them mutating is not so small. Indeed it is likely that a fertilized egg has a chance of 1 in 10 and probably higher of having, somewhere among its thousands of genes, a new mutant.

An example of a mutant gene is the one symbolized by *s* that causes sickle cell anemia. This is a severe, often fatal, anemia, characterized, as the name implies, by some crescent-shaped red blood cells. The severe disease occurs only when the person has two *s* genes, having inherited one from the mother and one from the father. A person with only a single dose of the gene is almost normal, but has a slight anemia which can usually be detected by laboratory tests.

The *s* gene is typical of most mutant genes. It does a much greater amount of harm in double dose than in single dose. (Curiously, there are parts of the world where the mildly anemic single dose form is actually beneficial, for somehow these persons are more than normally resistant to one kind of malaria. Therefore, in some parts of Africa where this malaria is common, it is advantageous to carry one *s* gene, but not two. It is unusual, however, to find mutations that are advantageous, even under special circumstances such as these.)

effect of mutations on the population

Mutations and mutation rates have been studied in a wide variety of experimental animals and plants, and in man. There is one general result that clearly emerges: almost all mutations are harmful. The degree of harm ranges from mutant genes that kill their carrier, to those that cause only minor impairment. Even if we didn't have a great deal of data on this point, based on observation, we could still be quite sure on theoretical grounds that mutants would usually be detrimental. For a mutation is a random change. It is a random change in a highly organized,

reasonably smoothly functioning living body. A random change in this highly integrated system of chemical processes is almost certain to impair it – just as a random interchange of connections in a television set is not likely to improve the picture.

A second conclusion that is reached when a careful study of mutations is made, is that mildly harmful mutants far outnumber those causing gross or obvious changes. The best data on this point comes from the fruit fly, *Drosophila*, where geneticists have been able to make precise measurements of mutational damage. These studies show that for each mutant that causes a visible effect – crooked legs, changed eye color, misshapen wings – there are about twenty that lead to death in the pre-adult stages. And for each one that causes an early death, there are about five that cause, not certain death, but a statistical increase in the death rate. From this we infer that the most frequent mutants in man are not those leading to freaks or obvious hereditary diseases, but those causing minor impairments leading to higher embryonic death rates, lowered life expectancy, increase in disease, or decreased fertility. Thus most of the damage is probably the same sort that we already have from other causes. Ordinarily it will be impossible to determine in any specific instance whether a particular impairment is or is not the result of a mutation.

One might think that mutants that cause only a minor impairment are unimportant. But this is not true for the following reason: A mutant that is very harmful usually causes early death or sterility. Thus the mutant gene is quickly eliminated from the population. On the other hand, a mutant that causes a smaller amount of harm will persist longer, and therefore affect a correspondingly larger number of persons. On the average the larger number affected roughly compensates for the lesser effect on each individual. Since minor mutations can thus cause as much harm in the long run as major ones, and occur much more frequently, it follows that most of the mutational damage in a population is due to the accumulation of minor changes. This means that an estimate of mutational damage based only on obvious hereditary diseases and conspicuous abnormalities is a gross underestimate of the total impact. The effect of minor mutations, though intangible in the sense of being indistinguishable from the other ills we are beset with, is probably in the aggregate much more important.

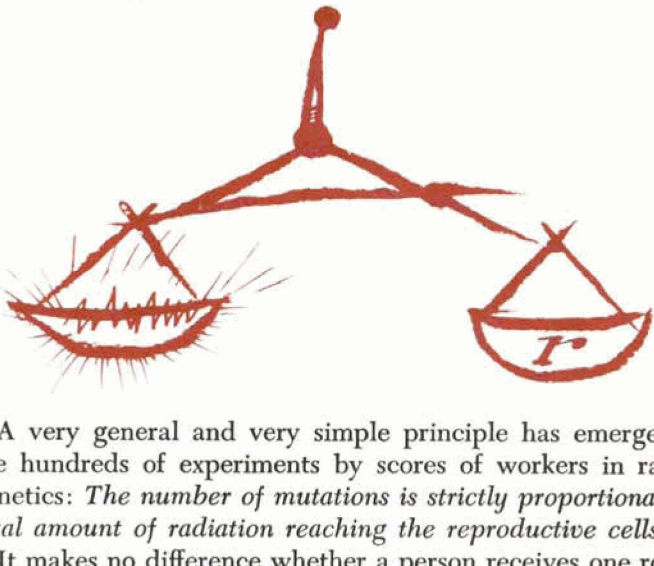
radiation and mutations

In 1927, H. J. Muller, then at the University of Texas, but now at Indiana University, made the discovery that X-rays produced a large increase in the mutation rate in the fruit fly, *Drosophila*. The results were soon confirmed by studies on various animals and plants and with various ionizing radiations, so it is now a well-established principle that any high energy radiation can cause mutations.

You might ask if any information has been obtained directly from studies on man. Such information is hard to obtain for one obviously cannot perform either experimental radiation or experimental matings. Nevertheless, there is a little information. The studies of the children of Hiroshima and Nagasaki survivors have been inconclusive, but two other studies offer some evidence. One was a mail questionnaire study that showed a slightly lower proportion of normal births in the families of American radiologists than in a group of pathologists who did not use X-rays in their profession. The second study, done in France, showed a deviation in the sex ratio of children of parents who had heavy X-ray treatments for various diseases. Both studies are dependent on mail questionnaires, and for this and other reasons neither is conclusive. Together, however, they are strongly suggestive.

Much stronger evidence comes simply from the consideration that man is, after all, an animal. So far, of all the dozens of plants and animals that have been adequately tested, not one has failed to produce more mutations when radiated, and it is improbable in the extreme that man differs from all others in this respect. For this reason, as well as because of the supporting data just mentioned, geneticists have no doubt that radiations do increase the mutation rate in man.

From the standpoint of future generations the important cells in the body are the reproductive cells in the testes or ovaries, for from these the sperms and eggs are derived. Although mutations occur and are influenced by radiation in all parts of the body, it is only those that occur in the reproductive cells that matter from the standpoint of heredity. The amount of genetically significant radiation is that which reaches the reproductive cells prior to reproduction – from this standpoint, mutations in other parts of the body, or in a person who will not have future children, can be ignored.



A very general and very simple principle has emerged from the hundreds of experiments by scores of workers in radiation genetics: *The number of mutations is strictly proportional to the total amount of radiation reaching the reproductive cells.*

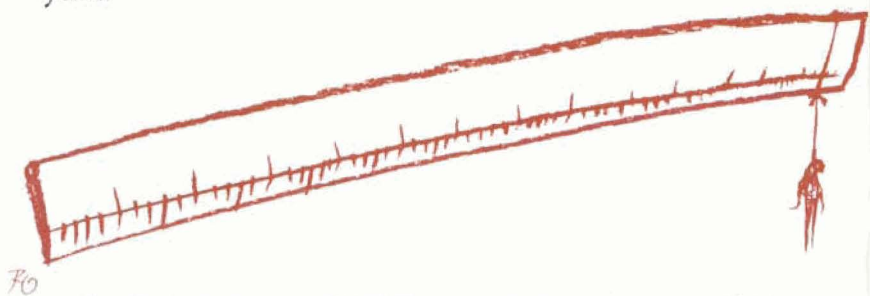
It makes no difference whether a person receives one roentgen per year for ten years, or 10 roentgens all at once – the genetic effect is the same. And if he receives 20 roentgens, the genetic risk will be twice as great as if he received 10. There are exceptions to this principle in plant and animal experiments, but they are at much higher doses than we are concerned with here.

Geneticists are convinced that there is no threshold, i.e. no dose too low to produce any mutations. Thus there is no such thing as an entirely harmless or "safe" dose. Each dose, however small, carries a risk proportional to that dose.

distribution of mutational damage in time

When a mutation occurs it may cause damage in the first generation of children, or if it is of the type that causes damage only when in a double dose (i.e., is *recessive*) hundreds of generations may intervene before the disease occurs—and there are all grades between these extremes. The best overall summarizing statement would probably be something like this: Following an increase in the mutation rate, the resulting effects would be spread very thinly through many generations. Although the amount of harm would be greater in the first generation children than in any other single generation, the first generation effect is nonetheless a very small fraction of the total. Geneticists have estimated that about half the damage would occur in 30-50 generations (this may be called the "half-damage time" by analogy with the half-life of a radioactive element).

So when we consider genetic effects, we are dealing with the longtime future of man – for 30 generations is about a thousand years.



The fact that mutational damage is spread over such long periods of time makes it clear why the inconclusive results of the studies of children of Japanese A-bomb survivors should not be interpreted as evidence for the nonexistence or nonimportance of radiation-induced mutations in man. If a large effect appeared in the first generation, the total effect would have to be enormous. The second reason why actual demonstration of radiation-induced mutation in man is so difficult is that the mutational effect, detected as malformations, stillbirths, various diseases, and increased death rates, are mimicked by various other causes including spontaneous mutations.

quantitative estimates

The conclusions of the previous section – that any amount of radiation to the population is genetically damaging – is firmly established and generally accepted. But when it comes to saying how much damage, there is much greater uncertainty.

The difficulty comes from the necessary dependence on experimental animals. This alone is not too bothersome, for we often depend on animal data for biological and medical conclusions. The trouble is that, although all the laboratory species show an increase of mutation with radiation, the amount of increase is different in different animals. For example, typical rates in the house mouse are some fifteen times higher than those in *Drosophila*. Unfortunately there are no other quantitatively reliable data from any mammal. Therefore we have little choice but to consider that men are mice as far as response to radiation is concerned.

A large study involving hundreds of thousands of mice has been carried out by Dr. W. L. Russell at the Oak Ridge Laboratory. These show that one roentgen produces about one mutation in four million genes. It would require some 30-60 roentgens to produce, in mice, a mutation rate equal to that which occurs spontaneously in those human genes that have been adequately studied. Assuming that human genes have the same radiation sensitivity as mouse genes, a dose of some 30-60 roentgens would double the existing rate.

The period between birth and reproduction in man is about 30 years. During that time the amount of natural radiation received is about 3-5 roentgens. If the estimates from the preceding paragraph are correct, this is only a small fraction of the amount required to account for the existing rate of spontaneous mutation, so it must be that the majority of mutations are not caused by natural radiations. Perhaps as many as 90 per cent are due to causes unrelated to any radiation, though the fraction may be much less.

medical radiation

In the United States, where there is a wide use of gamma and X-rays for diagnostic and therapeutic purposes, medical radiations add appreciably to the total received. The average 30-year-dose to the reproductive cells has been estimated variously from 2-5 or more roentgens. This figure is very difficult to assess with any accuracy, but it is clear that the amounts from natural sources and from medical radiations are of a comparable magnitude. It is likely that in the future, by better means of shielding the reproductive cells, by machines that use various technical innovations to give a better picture with a smaller dose, and by the discovery of other diagnostic and treatment methods, the dose can be decreased substantially without detriment to the quality of medical practice.

By contrast, the 30-year-dose from fallout if the rate of the last five years continues, will be 0.1 roentgen, more or less. (Dr. Libby of the Atomic Energy Commission gives the yearly dose from fallout in the United States as .001 to .005 roentgens per year, or 0.03 to 0.15 in 30 years. British scientists, in a report prepared for the United Nations, give a 30-year estimate of about 0.6 roentgens for a person spending 24 hours per day in the open unprotected – the average individual, they estimate, would receive about 0.03 roentgens.) So we must conclude that fallout, at present rates, is a small fraction (less than 5 per cent, perhaps only 1 per cent) of natural radiations. Therefore the mutations induced by bomb tests are a small fraction of all radiation-induced mutations, and an even smaller fraction of all mutations.

One must remember, however, that nuclear test explosions send fallout all over the world, so that some 2.5 billion persons are exposed. Even a very tiny risk, when multiplied by such large numbers, becomes impressive. Various geneticists have attempted estimates, all making use of data from experimental animals and using various necessary (but unprovable) assumptions, of what might be expected. For example, I have computed that if the world's population is exposed to 0.1 roentgen, there may be some 8,000 children in the next generation born with gross physical or mental defects, or a total of 80,000 in the longtime future. Likewise I have estimated 40,000 embryonic and infant deaths in the next generation, or a total of 700,000 for all time. As stated earlier, such figures based on tangible effects probably underestimate the total effect.

Let me emphasize that these figures may be *grossly in error*, but they do suggest that the very tiny fraction is a very large number of persons when the whole world population is involved.

conclusion on genetic effects

World-wide fallout at the present rate of weapons-testing contributes an amount of radiation that is only a small fraction, probably 1 to 5 per cent of natural radiations. Further, geneticists believe that only a fraction (perhaps 10 per cent) of spontaneous mutations are radiation-induced. Thus the present rate of testing will add only a very small fraction, perhaps less than 1 per cent, to the mutations occurring spontaneously. Thus the amount of human death, disease, and misery from fallout will be only a tiny fraction of that which occurs for other reasons.

On the other hand, the number of persons exposed to fallout is as large as the world population, and this means that spread over the whole world in space, and centuries in time, will be tens of thousands or more persons who will be diseased, or deformed, or will die prematurely or be otherwise impaired as a result of tests already done. The fraction is tiny, but the numbers are enormous.

SOMATIC EFFECTS OF RADIATIONS

IN considering the effects of radiations on the person receiving them, rather than on his descendants, we find again that information is not as solid as we should like. Especially difficult to assess are effects of very low, chronic doses such as might be expected from fallout.

effects of large doses

There is now considerable information about what happens with large doses. It comes from carefully controlled animal experiments. Also it has been possible to learn a great deal from direct human experience – victims of radiation accidents, the people of Hiroshima and Nagasaki, the Marshall Islanders injured by the test explosion of 1954, and persons receiving heavy radiation treatment – though often the exact dosage is not known. For the average person about 500 roentgens over the whole body in one dose is enough to cause death. Much larger doses can be tolerated on a small part of the body; for example, some X-ray therapy involves much larger doses, but to a small area. Lesser doses cause internal bleeding, vomiting, and hair loss. Below 100 roentgens usually no symptoms are noticed, but doses as low as 25 roentgens can cause detectable changes in the white blood cells.

All of these tragic consequences would be found in large numbers in the event of a nuclear war, but they occur at doses much (hundreds of times) higher than those due to fallout.

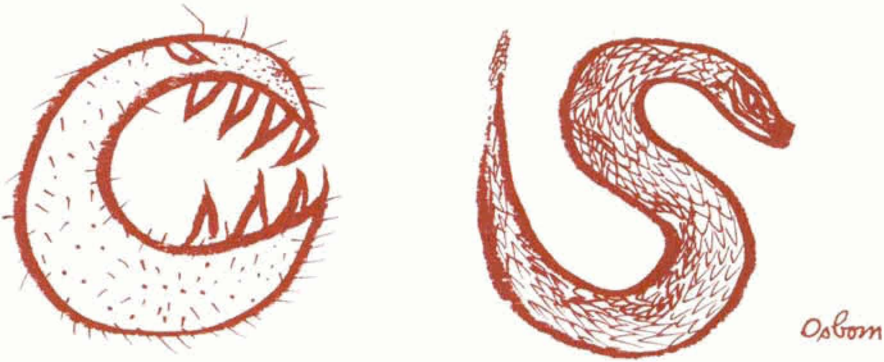
delayed effects

Radiation also causes long delayed effects. One is cancer; another is leukemia, a malignant disease of the white blood cells. Another is a general shortening of the life expectancy.

What makes these long delayed conditions of special significance is that there is some evidence that they are like genetic effects in having no threshold dose. We shall return to this topic later. *(See pages 22-24).*

cesium and strontium

In worldwide fallout these two elements are of special significance. Both disintegrate slowly, having radioactive half-lives of about 30 years, so that only a small part of the radiation is "wasted" in the stratosphere. Also both have chemical properties, such as solubility, that increase their probability of getting into the body.



Cesium-137 shares many chemical properties with potassium. After getting into the body it is distributed rather widely throughout various tissues. The radiation emitted is gamma, which is penetrating enough so that the radiation effects occur quite uniformly throughout the body. It is gradually excreted at such a rate that a little less than a fourth remains at the end of a year. For all these reasons, cesium-137 doesn't present a unique problem – it simply adds to the general level of radiation throughout the body and to whatever genetic and somatic effects are already occurring.

Strontium-90 presents quite a different problem. After reaching the earth's surface it may get into the soil and be taken up by the roots of plants. The plants may be eaten by humans, though in the United States more likely by farm animals. In turn, we eat the animals, or their products such as milk.

Strontium is chemically similar to calcium, and tends to follow the same course as calcium in the soil, in plants, in animals, and in the human body. Because we in America get much of our calcium from milk products, the most important path of strontium to the body is: soil – grass – cow – milk – human.

Once strontium gets into the body, again acting like calcium, it tends to be deposited in the bone. There it remains for many years, continuing to send off beta radiations.

As described earlier, beta radiation does not travel far in the body before being absorbed. Therefore almost all the damage done by strontium-90 is in the bone itself. One can produce bone cancer in experimental animals by feeding them strontium-90. There is also the possibility of leukemia, for some of the white blood cells are produced in the bone marrow.

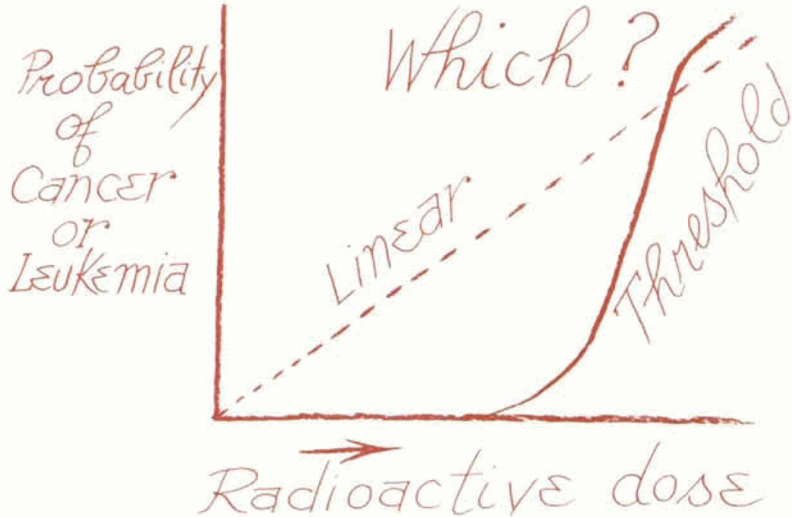
That gamma radiations from cesium-137 and the bone irradiation from strontium-90 are dangerous in large amounts is clear enough. But what about the low levels resulting from fallout?

is fallout a somatic hazard?

The fact is that no one knows. The answer hinges largely, as it did with genetic damage, on whether there is a threshold.

It may be that cancer, leukemia, and life shortening are like X-ray skin burns and occur only after a minimum threshold dose with all lower doses being harmless. But, on the other hand, these delayed effects may be like mutations in that any dose, no matter how small, involves a proportional risk.

You might ask at this point: Why are geneticists so sure that there is no threshold for mutations while there is so much uncertainty about somatic effects. One would think it would be easier to decide the point experimentally for somatic effects than for mutations since only one generation is involved. The answer lies mainly in the depth of our basic understanding. The laws of inheritance and mutation are among the best understood of any biological processes. There is a body of well-established theory that can serve as a guide to informative experimentation and



provide answers to questions inaccessible to experimental study. On the other hand, cancer and aging are not nearly so well understood. They are among the most perplexing mysteries.

Most animal experiments have been done at high acute doses and the results have generally been interpreted as favoring a threshold. On the other hand, the Hiroshima and Nagasaki incidence of leukemia, when plotted against the estimated dose received, suggest a straight line relationship. Some other sources of data (patients who had therapeutic radiation, children who received radiation as embryos when their mothers had preparturition X-ray measurements, children treated for enlargement of the thymus gland) are also in rough agreement. Furthermore, there are some biophysical arguments in favor of no threshold.

If there is no threshold for cancer, leukemia, and life expectancy reduction, one can make computations as to the number of cases that will occur as a result of fallout, such computations being, of course, subject to a very wide margin of uncertainty. As with genetic effects, the estimated effect is a very small fraction of the existing cases of the diseases. *But considering the* *world population, tens of thousands of cases of bone cancer and leukemia are involved.*

The main enigma is strontium. On the basis of radium experience, the National Committee on Radiation Protection recommends as the maximum permissible dose, a strontium level of 1000 "Sunshine units." (A "Sunshine unit," named for the AEC's "Project Sunshine," is measured in terms of the amount of radioactivity per unit of calcium; one S.U. delivers roughly .003 roentgens a year to the bone.) This is for those who, for occupational reasons, must be exposed to radiation; for the general population a dose one-tenth as large, 100 "Sunshine units," is recommended as the upper limit. Some have suggested a smaller limit for children.

In early 1957, according to the AEC, the average adult in the United States carried 0.1 to 0.2 S.U. An independent study from Britain gives 0.2, in good agreement. Young children, whose growing bones take up more calcium, and therefore more strontium, average about 0.5 S.U.

Only a fraction of the stratospheric strontium has fallen, and only a fraction of what has fallen has yet gotten into human bones. A reasonable estimate by the British Atomic Scientists Association is that the dose from tests through 1956 will total 4 S.U. by 1970. If the present rates of strontium-90 production continues indefinitely, the amount would eventually be 10-40 S.U., or .03 to .12 roentgens per year in the bone. This would be a substantial fraction of the natural radiation received by the bone, which is .10 to .15 per year.

*This is also 10-40 per cent of the maximum permissible concentration for the population. If we stay below the maximum permissible limit, we can't go too far above the recent average of 10 megatons a year.**

* Dr. Libby has concurred in recent findings that within a few years, if tests continue, the bones of young persons in the northeastern U. S. might contain one-tenth to one-fourth the maximum permissible strontium 90 (*N. Y. Times, August 26, 1957.*)

It must be emphasized that the maximum permissible concentration is necessarily arbitrary, for in the present ignorance one can only balance one set of intangibles against another.

conclusion about somatic effects of fallout

The first conclusion is that the amount of radiation from fallout is much too small to cause any of the symptoms of acute radiation exposure. We can also conclude, since the amounts of radiation, even in the bone where strontium-90 is concentrated, are so small relative to natural radiation that any effect must be small compared with that occurring for other reasons. However, long-continued testing at present rates can eventually bring the bone strontium level to an appreciable fraction of the background radiation level.

The amount of harm being done is unknown because of lack of knowledge about the existence or nonexistence of a threshold dose below which no harm occurs. If a simple proportionality exists, a number of instances of leukemia and cancer are being induced, and perhaps other diseases and some general life-shortening. The amounts would be a very small fraction of those cases of disease due to other factors. *The absolute numbers, however, considering the world population, would be large.*

On the more optimistic assumption of a threshold, there may be no harm done, provided the threshold is high enough so that no one exceeds it. Perhaps neither idea is entirely correct, but the truth lies somewhere between. In the present uncertainty, and because of recent evidence that the relation of dose to leukemia risk is one of simple proportion, it is prudent to base our tentative conclusions on the most pessimistic assumption.

other possibilities and risks

There has been considerable discussion recently about the possibility of "clean" bombs, that is, bombs that do not release radioactive products. The "dirtiness" of a bomb comes from fission rather than fusion processes and from soil, metal, or other debris that is included in the explosion. Thus by increasing the ratio of fusion to fission energy, and exploding the bomb high in the air, the explosion can be made "cleaner." How much further progress can be made in this direction remains to be seen. At present there are no clean bombs, only cleaner, according to recent testimony given before the Joint Congressional Committee on Atomic Energy.

The risks from fallout, whatever their magnitude, are infinitesimal in comparison with the consequences of a nuclear war. In addition to persons killed outright by the direct effects of explosions would be enormous numbers of delayed effects. The estimates for this and future generations made for present fallout would have to be increased, perhaps a hundred or thousand fold. A lethal dose is in the vicinity of 500 roentgens. If the consequence of a nuclear war were to expose the world's survivors to an average of 100 roentgens, this would be a thousand times the amount of radiation received by a generation from fallout at present rates.

As we make greater use of nuclear energy for peacetime uses, the radiation problem will increase. The problem of waste disposal becomes more and more difficult. No doubt these problems can be solved, and the benefits of carefully controlled atomic energy will outweigh the inevitable increase in genetic risk. But the control of radioactive products will be a continuously troublesome and expensive problem.

One point that deserves emphasis is that we know much more about radiation than we do about most of the environmental hazards of modern life. It is quite possible, indeed likely, that among the many new chemicals in our complex industrial society — smoke, food coloring, insecticides, smog, automobile exhausts, preservatives, drugs — some will be found to be a greater somatic or genetic hazard than radiation. It is to our great good fortune that the atomic age came after we had some knowledge of radiation dangers; we can, at least if we choose, now proceed into the future with due caution.

CONCLUSIONS

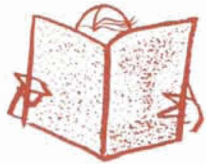
GENETICISTS agree that any amount of radiation is a genetic risk. Therefore fallout is doing some harm to future generations. This harm, if present rates continue, will be extremely small relative to the other hazards we face. At the same time, the number of persons at risk is very large, so we can be sure that a large number of future persons — tens or hundreds of thousands or more — will die, or be deformed, or diseased, or otherwise impaired as a result of bomb testing.

With somatic damage, no one can say for sure. Perhaps no harm is being done at present levels. The present rates can continue, though there is not room for much increase without exceeding the recommended permissible dose. On the other hand, with the more pessimistic assumption of a strict proportionality, some tens of thousands of bone cancers and leukemia cases may have been produced. Again, this is a small fraction of all cases.

Spread over the whole world in space, and over scores of generations in time, and not identifiable as due to radiation, the persons injured as a result of fallout will be lost in the much larger number due to other causes, and probably will not lead to any detectable change in the statistics. But if all the victims could be identified and assembled in one place at the same time, we would all regard it as a horrible tragedy.

These are the facts as they are known at present. Public officials must take them into consideration in formulating policies, and so must the individual thinking citizen in a democracy; for his is the ultimate responsibility for decisions.

WHAT TO READ



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