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DEPARTMENT OF THE ARMY
WASHINGTON 25, D. C.

RCC1.941116.010

IN REPLY REFER TO:

18 July 1956

MEMORANDUM TO: Chairman:
Mr. William H. Martin, Department of the Army

Members:
Mr. Girard Smith, Department of State
Mr. Ervin L. Peterson, Department of Agriculture
Mr. Charles F. Honeywell, Department of Commerce
Dr. Lowell T. Coggeshall, Dept of Health, Education and Welfare
Mr. A. Tammaro, The Atomic Energy Commission

Alternates:
Mr. George Spiegel, Department of State
Dr. George Irving, Department of Agriculture
Mr. Jacob M. Schaffer, Department of Commerce
Mr. George P. Larrick, Dept of Health, Education and Welfare
Dr. Charles Dunham, The Atomic Energy Commission

SUBJECT: National Academy of Sciences Report on the Biological Effects of Atomic Radiation

1. For your information is inclosed a copy from the recently publicized reports of the National Academy of Sciences Study Group on the Biological Effects of Atomic Radiation.

2. The preservation of food is included as a section of the studies, although the subject of predominant publicity in the press has been the conclusions of the genetic deliberations.

R. G. H. SIU
Executive Secretary
Interdepartmental Committee on Radiation Preservation of Food

2 Incl
1. Report to the Public
2. Summary Report

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OQMG - O/R&D
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THE BIOLOGICAL EFFECTS OF ATOMIC RADIATION

A REPORT TO THE PUBLIC

National Academy of Sciences—
National Research Council

THE BIOLOGICAL EFFECTS OF ATOMIC RADIATION

A REPORT TO THE PUBLIC

From a Study by the

NATIONAL ACADEMY OF SCIENCES

NATIONAL ACADEMY OF SCIENCES — NATIONAL RESEARCH COUNCIL
Washington
1956

THE BIOLOGICAL EFFECTS OF ATOMIC RADIATION

A Summary Report to the Public
from the National Academy of Sciences

Part I

INTRODUCTION

Whenever atomic energy is released, there are released with it certain invisible but powerful radiations. It has been known for many years that when these radiations strike living things they cause important changes that are often harmful. It is also known that the changes may not be limited to the plant or animal which receives the radiation, but may be passed on to succeeding generations. However, the details of the action, how much radiation will produce a given result, how much can be done to counteract the deleterious effects, these are largely unsolved problems.

There has always been some radiation in the environment. Radium and other radioactive elements in the ground together with cosmic rays from outer space produce a natural "background" over all parts of the earth. However, as atomic activity is stepped up throughout the world, the amount of radiation in our surroundings may be substantially increased. This could have profound effects on all forms of life. But there has been disturbingly little information about just what the effects may be.

In 1955 Detlev W. Bronk, president of the National Academy of Sciences, appointed a group of scientists to investigate the effects of high-energy radiation on living things. Funds were provided by the Rockefeller Foundation.

The study is divided into six parts, each assigned to a separate committee. The areas under consideration are (1) genetics, (2) pathology, (3) agriculture and food supplies, (4) meteorology, (5) oceanography and fisheries and (6) disposal of radioactive wastes. A list of the membership of each committee appears at the end of this report.

The scientists have now sifted the present knowledge in the field, and have marked out the areas in which further research is most needed. Their study will be a continuing one since many of the problems involve basic scientific questions which will take many years to answer. Also, new questions may be expected to arise as the uses of atomic energy expand.

The present report summarizes the findings to date. It is intended for the lay reader and extracts from the more detailed reports being published at the same time those aspects which are of most general interest. The purpose is (1) to tell the citizen what science has learned thus far about the potential effects of atomic radiation on himself and his progeny, and on the race as a whole; (2) to give him such information as scientists can now provide to help him participate more intelligently in making necessary public decisions about atomic energy.

It should be emphasized that he will find here only scientific data. Most of the decisions he will be faced with involve ethical, political, economic or military questions as well. These can be more usefully debated, however, against an adequate technical background.

Behind any discussion of radiation must necessarily loom the specter of full-scale atomic war. That a single thermonuclear weapon can cause severe radiation damage hundreds of miles beyond its area of immediate devastation is all too well known. That enough such weapons exploded in an all-out war might render the entire earth, or large parts of it, uninhabitable, is at least conceivable.

The actual results would depend on the number, the types and the location of the explosions that actually took place. There has been comparatively little attempt in the study thus far to estimate the possible courses of atomic warfare or to assess the biological consequences. The present emphasis has been on peaceful development.

It may be pointed out, however, that so far as radiation is concerned the two aspects are not entirely unrelated. In the first place, when a world-wide atomic power industry becomes fully developed, its accumulated waste products might represent more radiation than would be released in an atomic war. Of course, this radiation will be imprisoned, not broadcast. But the point underscores the magnitude of the coming problem.

Secondly, it becomes clear in this report that even very low levels of radiation can have serious biological effects. In several instances the size of the effect turns out to depend directly on the amounts of radiation. Thus, many of the disastrous consequences of atomic war are clearly implied in this investigation of peacetime problems.

Part II

BRIEF DIGEST OF FINDINGS AND RECOMMENDATIONS

It is generally agreed that, in the peacetime development of atomic energy, man has been lucky. He has been dealing with an enormous new force whose potential effects he has only dimly understood. Thus far, except for some tragic accidents affecting small numbers of people, the biological damage from peacetime activities (including the testing of atomic weapons) has been essentially negligible. Furthermore, it appears that radiation problems, if they are met intelligently and vigilantly, need not stand in the way of the large-scale development of atomic energy. The continuing need for intelligence and vigilance cannot be too strongly emphasized, however.

The problems of radiation fall naturally into two main classes: (1) the effects on human beings; (2) the various ways in which radiation can reach human beings through the environment.

Effects on Humans

The inheritance mechanism is by far the most sensitive to radiation of any biological system.

Any radiation which reaches the reproductive cells causes mutations (changes in the material governing heredity) that are passed on to succeeding generations.

Human gene mutations which produce observable effects are believed to be universally harmful.

Everyone is subjected to the natural background radiation which causes an unavoidable quantity of so-called spontaneous mutations. Anything that adds radiation to this naturally occurring background rate causes further mutations, and is genetically harmful.

There is no minimum amount of radiation which must be exceeded before mutations occur. Any amount, however small, that reaches the reproductive cells can cause a correspondingly small number of mutations. The more radiation, the more mutations.

The harm is cumulative. The genetic damage done by radiation builds up as the radiation is received, and depends on the total accumulated gonad dose received by people from their own conception to the conception of their last child.

So far as individuals are concerned, not all mutant genes or combinations of mutant genes are equally harmful. A few may cause very serious handicaps, many others may produce much smaller harm, or even no apparent damage.

But from the point of view of the total and eventual damage to the entire population, every mutation causes roughly the same amount of harm. This is because mutant genes can only disappear when the inheritance line in which they are carried dies out. In cases of severe and obvious damage this may happen in the first generation; in other cases it may require hundreds of generations.

Thus, for the general population, and in the long run, a little radiation to a lot of people is as harmful as a lot of radiation to a few, since the total number of mutant genes can be the same in the two cases.

It is difficult to arrive at a figure showing how much genetic harm radiation can do. One measure is the amount of radiation, above the natural background, which would produce as many mutations again as occur spontaneously. It is estimated that this amount is 30 to 80 roentgens.

(The roentgen is a unit of radiation. To give an idea of its value, the average dental X-ray delivers five roentgens to the patient's jaw, but only five thousandths of a roentgen of stray radiation to more remote parts of the body such as the gonads.)

It is also estimated that a dose of 10 roentgens to every person in the United States would cause something on the order of five million mutant genes which would then be a part of the population's inheritance pool. This figure is subject to considerable uncertainty.

At present the U. S. population is exposed to radiation from (a) the natural background, (b) medical and dental Xrays, (c) fall-out from atomic weapons testing. The 30-year dose to the gonads received by the average person from each of these sources is estimated as follows:

(a) background - about 4.3 roentgens
(b) Xrays and fluoroscopy - about 3 roentgens
(c) weapons tests - if continued at the rate of the past five years would give a probable 30-year dose of about 0.1 roentgens. This figure may be off by a factor of five, i.e., the possible range is from 0.02 to 0.5 roentgens. If tests were conducted at the rate of the two most active years (1953 and 1955) the 30-year dose would be about twice as great as that just stated.

If the exposure of the general population to radiation is limited to levels which the genetics committee believes reasonable (see recommendations at the end of this part), there should be practically no pathological effects in the persons receiving the radiation.

Larger exposures (say 100 roentgens and up) of the whole body or a large part of it are generally harmful when received in a single dose. (Much higher doses may, however, be safely and usefully delivered to limited portions of the body under the controlled conditions of medical treatment.) Very little is now known about how to treat the pathological effects of radiation or how to protect the body against them in the first place. Much research is needed in these fields.

One of the effects is a shortening of life. This seems to involve some generalized action. Irradiated individuals may age faster than normally even if they do not develop specific radiation-induced diseases like leukemia. It has not been shown that exposures small enough to be genetically tolerable have this effect. Furthermore, the permissable exposure levels that have been established for persons working with radiation appear to be within the limits of safety. However, it is not yet known what minimum dose, if any, would be necessary to produce a statistically noticeable reduction of life span when very large numbers of people are concerned.

Environment and Food Supply

Radiation in the general environment has not yet become a serious problem. In a few decades, however, radioactive waste products from atomic power plants will represent an enormous potential source of contamination. How much of this radioactivity will actually reach the population depends on how successfully it can be kept out of the great network--ocean and air currents, food and water supplies--which connect man to his surroundings.

At present test explosions of atomic weapons are the only significant source of radiation in the general environment, above the natural background.

Meteorologists have found no evidence that atomic explosions have changed the weather or climate. Nor do they believe that continued weapons tests, at the same rate and in the same areas as in the past, would have such an effect.

Radiation from explosions passes into the atmosphere and much of it eventually returns to the ground as "fall-out."

Fall-out divides into three classes: (1) close-in--material that comes down within a few hundred miles of the explosion and within 10 to 20 hours, (2) intermediate--material that descends in a few weeks after the explosion, (3) delayed--material that remains in the air for months or years.

Close-in fall-out from test explosions affects only restricted, uninhabited regions.

Intermediate fall-out would descend very slowly if it were pulled down only by gravity. It is mostly washed out of the air by rain and snow. It spreads over large parts of the earth, but its effect over a small area may be accentuated if there is heavy precipitation while the radioactive cloud is overhead.

Delayed fall-out is stored for long periods in the stratosphere. Meteorologists know very little about the interchange of air between the stratosphere and lower layers, so they cannot predict exactly how long the material will stay up, or where it is likely to descend.

At this point the oceans are not receiving any significant quantities of radioactive material. But eventually they will undoubtedly be used as a repository for some of the radioactive waste products of atomic power plants.

Before this can safely begin on a large scale, much research is needed to determine the mixing rates between various parts of the seas. Materials deposited in some of the deep parts of the ocean may remain there 100 years or more, so that most of their radioactivity would be gone before they reach surface water. On the other hand, material dumped into coastal and other surface waters would directly affect marine life and, within a few years, would contaminate all parts of the world because of the relatively rapid circulation of surface layers.

Radioactive tracers can be used to chart ocean and air currents and to study the interrelationships of marine animals. Many important experiments in these fields will be possible only within the next 10 or 20 years. Increasing radioactive contamination of the sea and atmosphere will make it impossible after that to detect the tracers against the heightened background.

Radiation from fall-out inevitably contaminates man's food supply. Radioactive elements in the soil are taken up and concentrated by plants. The plants may be eaten by humans, or by animals which in turn serve as human food.

At present the contamination is negligible. But the maximum tolerable level is not known. There is not nearly enough information about the long-term biological effects on man or animals from eating radiation-contaminated food. Research in this area is urgently needed.

Probably the most important potential food contaminant is strontium 90--a radioactive element that concentrates in bone tissue. Already, detectable although biologically insignificant traces of it have turned up in milk supplies thousands of miles from the site of atomic explosions.

Food from the oceans is also subject to radioactive contamination. Marine plants and animals extract and concentrate various radioactive elements that get into sea water. The concentration is cumulative, increasing as it proceeds up the chain from microscopic plankton to edible fish.

Properly used, radiation can enhance man's food supply rather than damage it. Radiation techniques have already opened important new fields in agricultural research and will undoubtedly become increasingly valuable. No drastic change in agricultural production appears imminent, however.

Tracer studies will help us understand basic metabolic processes in plants and animals. They will also be applied to practical problems such as the use of fertilizers.

Mutation rates in plants are being artificually speeded up with radiation in the hope of producing new and superior strains. Thus far, only a few new economic varieties have been found, but the method is promising. The use of radiation to sterilize packaged food may have dramatic impact on food technology by reducing the need for refrigeration and extending the shelf-life of many products.

Holding radiation to a tolerable worldwide level will require adequate methods for disposing of, or, rather, for containing radioactive wastes from power reactors.

Some of these wastes will remain dangerously radioactive for centuries.

Research has indicated some apparently feasible systems for controlled disposal, but none is yet at the point of economic operating reality.

The major problem in routine disposal is what to do with the wastes resulting from the processing of reactor fuel. The wastes from normal operations of reactors themselves can be more easily handled.

A second major problem is to anticipate the accidents that will inevitably occur and to set up safety standards which will insure that they do not become catastrophes.

Considered in this light, it appears feasible to use nuclear reactors in central station power plants and in naval vessels.

Recommendations

In the light of these findings the study committees have made a number of recommendations. Those of the genetics committee apply most directly to all of us. They are:

(I) Records should be kept for every individual, showing his total accumulated lifetime exposure to radiation.

(II) The medical use of Xrays should be reduced as much as is consistent with medical necessity.

(III) The average exposure of the population's reproductive cells to radiation above the natural background should be limited to 10 roentgens from conception to age 30.

(IV) The 10 roentgen limit should be reconsidered periodically with a view to keeping the reproductive cell exposure at the lowest practicable level.

(V) Individual persons should not receive a total accumulated dose to the reproductive cells of more than 50 roentgens up to age 30 years, and not more than 50 roentgens additional up to age 40. (About half of all U. S. children are born to parents under 30, nine-tenths to parents under 40.)

Other recommendations of general interest are:

(VI) Techniques for monitoring worldwide fall-out should be further improved.

(VII) Measurements of the storage of radiation in the stratosphere should be continued and extended.

(VIII) A national agency should control and keep records of all dumping of radioactive material in the ocean.

(IX) An international body should set up safe standards for the marine and air disposal of radioactive materials as soon as possible, based on current knowledge.

(X) Research in marine disposal should be carried out on a cooperative international basis.

(XI) Until advances in reactor technology substantially reduce potential hazards buildings that house reactors located near populated areas should be sealed against the release of radioactive materials in the event of accident.

(XII) Research should be continued and accelerated, particularly in the fields of:

Fundamental genetics, mammalian genetics, human and population genetics

Pathological effects of radiation

Mixing between various parts of the atmosphere

Mixing between various parts of the oceans

The role of plants and animals, both on land and in the oceans, in concentrating radioactive materials

The tolerable levels of radioactivity in human and animal food

Geophysical and geochemical aspects of the ultimate disposal of radioactive wastes

Selection of biologically suitable sites for various atomic facilities

Safety devices for the control of accidental power surges in reactors

Part III

THE NATURE OF RADIATION

Broadly speaking, radiation is a way in which energy moves from one place to another. Thus, the energy released when a stone is dropped into water radiates away in circular waves. Sound energy radiates from a speaker's mouth to a listener's ear; light and heat energy radiate from the sun to the earth. Electrons, radiating from a hot wire, provide the energy that forms the picture in a television set. In the first four examples the radiation consists of waves--water waves, sound waves, light waves, heat waves. In the last, the radiation is a stream of minute particles.

Here we are concerned with atomic radiation. It also transports energy, carrying it away from over energetic atoms. Xrays, the most familiar example, are waves, like light waves, only very much shorter. To give some idea of the scale, a water wave or a sound wave may be inches or feet long; a light wave is about a hundred thousandth of an inch long; a medium-short Xray, about a billionth of an inch. Another group of atomic radiations, called gamma rays, are like Xrays, but are usually still shorter. Their wave length goes down to about a 10-billionth of an inch.

One of the major discoveries of modern physics is that the shorter the wave length of any wave radiation, the more energy each unit of it carries. Hence, Xrays and gamma rays are enormously more energetic than light. They penetrate much farther into all kinds of matter, and they produce much larger effects.

In addition to waves, atoms are now known to radiate a great variety of particles. These are all unimaginably tiny (measured in 100-trillionths of an inch,) unimaginably light, and known to us only indirectly through their effects. Some of the more important particles are:

Electrons. The lightest particles, carrying a negative electric charge. Radiation electrons are sometimes called "beta rays."

Protons. About 2,000 times as heavy as electrons and positively charged.

Neutrons. Like protons, but uncharged.

Alpha particles. Each one is an assemblage of two protons and two neutrons.

What Produces Radiation?

Atomic radiation is given off by atoms which have more than the normal complement of energy--"excited" atoms in the physicists' phrase. Before describing excited atoms, however, we should pause very briefly to recall what an atom is. Every atom is composed of a tiny, positively charged "nucleus" surrounded by a cloud or swarm of negative electrons. The nucleus accounts for almost all the atom's weight and is composed of protons and neutrons.

The number of protons in a nucleus determines the chemical properties of the atom; each element has a unique and characteristic number of protons. The number of protons and neutrons together determines the weight of the atom. Two atoms having the same number of protons but different numbers of neutrons are said to be "isotopes" of the same element.

How does an atom get "excited?" One way is to be struck by a projectile. There is nothing very mysterious about this. If a bullet strikes a metal target, energy is added to the target--it is excited. This energy is then radiated away, in the form of waves which carry off the noise and heat of impact. There may also be particle radiation if the bullet knocks some pieces out of the target. In the same way, a bullet of atomic dimensions excites an atom that it strikes. The excess energy is radiated away in the form of waves (Xrays, gamma rays), particles (fragments from the target atoms) or both.

In an Xray machine, a stream of fast-moving electrons is made to strike a metal target. This excites some of the electrons in the atoms of the target. In the process of giving off the excess energy thus gained, the atomic electrons send out Xrays.

With the exception of Xrays, the radiation we are interested in comes from the nuclei of atoms rather than from their electron clouds. The big "atom-smashing" machines one reads about are simply devices for hurling various particles against nuclei. The target nuclei then spew out radiation, including gamma rays and a great variety of particles.

Not all radiation comes from atomic collisions, however. Some atoms are naturally excited, and emit radiation spontaneously. These are the atoms of radioactive substances such as radium. The nuclei of radioactive atoms erupt from time to time, giving off alpha particles, electrons or gamma rays.

Since each atom is characterized by the number of particles in its nucleus, when a radioactive nucleus throws off a particle the atom changes either into another element or into another isotope of its own species. The new nucleus may in turn be unstable and emit further radiation. Eventually, after a series of transmutations, every radioactive atom ends up as a stable element and stops radiating. For example the familiar radioactive elements such as radium and uranium end up as lead.

Different radioactive elements vary greatly in the frequency with which their atoms erupt. In some substances eruptions are comparatively rare. The atoms are somewhat like popcorn that is just beginning to heat up--only an occasional kernel pops. In other substances the atoms "go off" very frequently, like popcorn that is fully heated. Those substances in which there are infrequent explosions are comparatively weak sources of radiation, since radiation is produced by the explosion. On the other hand, these materials have a long life--that is, it takes a long time before all their atoms have transmuted themselves into other elements. Those in which explosions are frequent radiate strongly but have a short life. The time spread here is enormous. Short-lived radioactive substances may exhaust themselves in minutes, seconds, even millionths of a second. Long-lived materials may remain little changed for thousands, even millions of years.

The rate of radioactive decay is usually measured in "half-life"--the time required for half of any amount of radioactive material to transmute itself. Thus, if the half-life of a substance is one hour, half of any starting amount will be gone in an hour, half of what is left will go in the second hour, and so on. In ten half-lives, the amount of any radioactive substance is reduced to one-tenth of one percent.

Two important sources of radiation, as we have said, are naturally radioactive atoms and atoms made artificially radioactive by bombardment. We also receive radiation from the high-energy particles called cosmic rays, which rain on the earth from outer space. As the power program expands, however, the radiation from these other sources will fade into insignificance compared with that from the basic atomic energy process--nuclear fission.

When certain atomic nuclei, notably those of uranium and plutonium, are struck by neutrons, they do not radiate in the usual way. Instead, they split into two roughly equal parts and give off a large burst of energy. It is this energy that provides the explosive power of an atomic bomb, and that can be converted into useful power in an atomic pile.

Our concern is not with the energy, but with the nuclear fragments that are produced--the so-called fission products. The point is that in even the smallest bomb, or the most modest experimental nuclear reactor, there are trillions upon uncounted trillions of these fragments. The fission products are invariably unstable atoms; every one of them is radioactive. They include a wide variety of radioactive elements, ranging from very short-lived to very long-lived ones. The more bombs that are exploded, the more of these radioactive fragments are scattered broadcast over the earth. The more power reactors that go into operation, the more radioactive material must be disposed of. The disposal problem will arise chiefly when spent fuel from reactors is "processed;" that is, when the accumulated fission products are removed and the fuel reconstituted for further use.

Measurement of Radiation

The strength of radiation can be measured in many different ways. The unit we are using in this report is called a roentgen. Its technical definition* involves the ability of radiation to knock electrons out of air molecules (i.e., to ionize them). This is, unfortunately, not very meaningful to a non-specialist. As has already been pointed out, a rough idea of the size of the unit can be obtained from the fact that an average dental Xray delivers five roentgens of radiation to the skin of the patient's jaw, (but only five thousandths of a roentgen to parts of the body as distant as the gonads.)

What Does Radiation Do to Living Things?

This is the big question being dealt with in the study. In a very general way it is not hard to answer. When radiating waves or particles pass through any substance, at least some of them bump into molecules.

*The definition actually reads: "A roentgen is the quantity of radiation such that the associated corpuscular emission per 0.001293 grams of air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign."

The effect may be no more than to knock a few electrons out of the molecules, or it may be more drastic. But even if just a few electrons are knocked loose, the molecules become very active chemically, and form new combinations. Now a living cell is a marvelously delicate balance of interacting materials. Each molecule must be just what it is to play its proper role. Hence any chemical change in a cell, however slight, may have serious effects. It may substantially change the normal life processes, or even kill the cell.

When a complex organism is exposed to radiation the degree of damage, if any, depends on which of its body cells have been affected. The more vital parts are generally some distance in from the surface. Hence radiation coming from the outside is more harmful if it can penetrate to these parts than if it cannot. Xrays and gamma rays are very penetrating; particle radiation much less so. Most of the energy in a beam of particles is lost in the outermost layers of any organism it strikes. Radiation may also originate inside the organism. (Plants may take radioactive material up from the soil, animals may eat or inhale it). If the material concentrates in or near vital tissue, its radiation need not be penetrating to be very damaging.

What Radiation are We Exposed to?

Wherever one goes over the surface of the earth, there is always a small amount of radiation, more in some places than in others. It is called "background" radiation. It comes from two sources. One is the naturally radioactive substances--uranium, radium and so on--that are found in rocks and the soil. Of course, the percentage of radioactive deposits varies widely from place to place. The other is cosmic radiation. Cosmic rays are absorbed as they pass downward through the atmosphere, so that background radiation from this source is greater the higher one goes.

There are naturally-occurring radioactive atoms within living plants and animals, as well as in the earth. Thus every living thing is exposed to its own radiation as well as that from the external background.

Over and above the background, there are the various forms of manmade radiation to reckon with. At this point, in industrially advanced countries, by far the most important are medical and dental Xrays. The average U.S. citizen now receives roughly the same amount of radiation, over his whole body, from Xray and fluoroscopic examination as from the natural background.

Another source of radiation--a minor source so far-- is "fall-out" from atomic explosions. Every bomb or "device" that is set off throws into the air a huge cloud of radioactive particles, some of which are carried great distances by the winds of the upper air, and settle out gradually over the whole earth.

At the present time, atomic reactors are not a factor in the general radiation picture. But when large numbers of nuclear power plants are in operation, the output of radioactive fission products will be enormous. The ingenuity and care used in the management and release of these wastes will determine how much of their radiation passes into the general environment.

Part IV

SUMMARIES OF THE STUDY COMMITTEES' REPORTS

1. Genetics

We come now to the findings of the study committees. There are at least two good reasons for beginning with genetics. All of us tend to be more concerned for our children than for ourselves. And, as we shall see, the inheritance mechanism is by far the most sensitive to radiation of all biological systems.

Only the high points of what the genetics committee has to say are presented here. The problems of human genetics are complex and subtle, and a brief statement cannot do them justice. The full report has been written for a general public, and copies of it are available.

A summary of the committee's findings will not be very meaningful unless one knows a little about how biological inheritance works. The following paragraphs are a very brief, and oversimplified outline of a few of the fundamental facts of genetics.

Every cell in the human body (and in every other living organism) contains an enormous collection of tiny units called genes. Taken together they substantially determine all the characteristics the individual is "born with." Each person gets his genes from his parents, who got them from theirs, and so on.

Genes come in pairs, one of each pair inherited from the father and one from the mother. Every characteristic is governed by one or more pairs. For example, there are genes which have to do with hair color, others which control stature and so on.

This is the way the gene pairs are acquired: Sperm and egg cells have single sets of genes rather than pairs. When a sperm and egg unite to form the first cell of a new embryo, there is a new double set, half coming from the father and half from the mother. As the embryo develops, this set is duplicated over and over again through the successive divisions of the cell, so that every cell in the body of the fully developed infant has an essentially identical set of genes.

Just which gene a child inherits from each of his mother's and father's gene pairs is a matter of chance. Sperm and egg cells are produced by a splitting of cells in the sex glands or gonads. When the cells split, the gene pairs divide up at random.

From all this it is obvious that the two genes in each pair are not necessarily or even usually identical. Thus, if a child inherits a gene tending to produce red hair, say, from his father, there is an excellent chance that the corresoonding maternal gene will have some other color tendency. How is the characteristic then determined? What color will the child's hair be? The answer is that in each pair of genes, one almost always has a stronger effect than the other and largely determines the characteristic involved. This is called a dominant gene. The weaker member is called a recessive gene. In the usual case, the recessive's effect is not completely submerged. Thus, in our example, the principal gene for red hair is recessive. The child who carries one such gene will have black hair, or brown or blond, but it will very likely have a rusty, or tawny tinge. To make him a true redhead, both of the principal genes would have to be the type for red. In general, a recessive characteristic can be fully realized only in the cases when both genes of a pair are the recessive type.

Mutations

The endless reduplication of genetic patterns, from cell to cell and from generation to generation, is not the least of the wonders of life; but the patterns are not eternally static. Every so often a gene changes or "mutates," and a characteristic of the organism is altered. Presumably a changeling gene undergoes some chemical rearrangement, although we do not yet know any of the details of the process. We do, however, know a number of ways to bring about mutations. Heat, certain chemicals and--especially--radiation will do it. And once changed, the new form of the gene is then passed on as faithfully as the old one was.

Now, as has already been pointed out, the processes of life are so delicately balanced that any change, any departure from the established order of things at the cellular level, is overwhelmingly likely to be for the worse. Mutations almost invariably harm the organism in which they occur.

To be sure, very infrequently a mutation will turn out to be helpful. Evolution has depended on a sequence of rare mutations, each of which produced an organism slightly better equipped than its ancestors to deal with the environment. Plant breeders are continually looking for helpful mutations that will give improved crop varieties. But the exceptions merely prove the rule: most mutations are harmful.

If mutation takes place in an ordinary body cell, the effect is usually not serious. In any case, the damage is primarily restricted to the individual in whom the change occurred.

But the situation is quite different if the gene affected is located in the reproductive cells of the sex glands. Then the damage can be passed on through the sperm or eggs produced by these cells, to the individual's children, thence to their children, and so on.

With this background, we turn to the committee's report.

Radiation Genetics - Basic Facts

To begin with, the group points out that most of what is known about genetics comes from studies on lower forms of life. Knowledge of human genetics is rather limited. Fortunately, the main pattern of heredity is the same for all forms of life reproducing sexually. Also, the action of high-energy radiations upon the genetic material is universally the same in principle.

Thus although there are many uncertainties about details and about certain numerical values, there is complete agreement among geneticists concerning a number of basic facts. These can be summarized as follows:

1) Radiations cause mutations.

2) Practically all radiation-induced mutations which have effects large enough to be detected are harmful.

   The change due to a mutated gene seldom is fully expressed in the first generation of offspring of the person who received the radiation. For mutant genes are usually recessive. If a child gets from one parent a mutant gene, but from the other parent a normal gene belonging to that pair, then the normal gene is very likely to be at least partially dominant, so that the normal characteristic will appear.

   But this is not all of the story. For, like the red-hair gene, the harmful recessive mutant genes are not usually completely masked. Even when paired with a normal and dominant gene, they still have some detrimental effect.

Thus, most of the harm from a radiation-induced mutation might remain unnoticed, for a shorter or longer time, in the genetic constitution of the successive generations of offspring. But the harm would persist, and some of it would be expressed in each generation. On the average, a detrimental mutation, no matter how small its harmful effect, will in the long run tip the scales against some descendant who carries this mutation, causing his premature death or his failure to produce the normal number of offspring. In this way harmful mutations are eventually eliminated from the population.

Although many mutations disturb normal development of the embryo, it is not correct to say that all, or even most mutations result in monstrosities or freaks. In fact, the commonest ones are those with the smallest direct effect on any one generation--the slight detrimentals.

3) Any radiation dose, however small, can induce some mutations. There is no minimum amount of radiation dose which must be exceeded before any harmful mutations occur.

4) Every generation of living things acquires some mutations from natural causes (background radiation and also heat and certain chemicals). These are called "spontaneous mutations," and are also nearly all harmful.

   We all carry a supply of spontaneous mutant genes. The size of the supply represents a balance between the tendency of old mutants to eliminate themselves, and the tendency of new ones to appear.

5) Additional radiation over and above the irreducible background produces additional mutations over and above the spontaneous mutations. To the best of our present knowledge, if we increase the radiation that reaches the reproductive glands by X percent, the number of mutations caused by radiation will also be increased by X percent.

   The total dose of radiation received by a person over his reproductive lifetime is what counts. The genetic damage done by radiation is cumulative.

6) From the above five statements a very important conclusion results. It has sometimes been thought that there may be a rate (say, so much per week), at which a person can receive radiation with reasonable safety as regards certain types of direct damage to his own person. But the concept of a safe rate of radiation simply does not make sense if one is concerned with genetic damage to future generations. What counts, from the point of view of genetic damage, is not the rate; it is the total accumulated dose to the reproductive cells of the individual from the beginning of his life up to the time the child is conceived.

Individual vs. Population

It is easy enough to say that radiation causes genetic damage, but to define and measure the damage is very difficult.

In the first place, there is more than one way to look at the problem. One may think primarily in terms of individual damage, including distress to persons, or in more abstract terms of the population as a whole.

Geneticists who emphasize the individual point of view are concerned especially with the risk to the descendants of individuals subjected to a great deal more than the average amount of radiation. From the population standpoint, however, what is important is the effect of the average dosage on the characteristics of people in general.

If the whole population of the United States received a small dose of extra radiation--say one roentgen--there is good reason to think that, among the next hundred million children to be born, several thousand would be definitely handicapped because of mutant genes due to radiation. These several thousand would, so to speak, be lost in the crowd. No one could trace the direct connection between their special handicaps and the radiation dose, since there would be many more children handicapped from other causes (e.g., spontaneous mutations).

On the other hand, if 10,000 individuals were exposed to a much larger dose of radiation (on the order of 200 roentgens) then there would be perhaps one hundred handicapped children of these exposed individuals, in addition to the number resulting from other causes. In this case the connection with the radiation risk could be more readily established by a statistical study, and society might be more impressed by the hundred cases than it would ever be by the several thousand more hidden cases.

In addition to this contrast in numbers of cases there is also a contrast in quality of damage. The personal viewpoint inevitably places great emphasis on the (relatively rare) instances of subnormal mentality, gross physical defects, or disorders which lead to the progressive deterioration and long delayed death of an apparently normal child. These tragedies cause severe distress to the affected individuals and their families, and are clearly the most tangible and personal part of the genetic damage. From the population viewpoint, however, this part of the damage may be equalled or even outweighed by much more minor handicaps to very many more persons.

There is still a third aspect to consider. A population that is exposed, generation after generation, to an increased amount of radiation will experience a rising death rate and a falling birth rate because of harmful mutations, until a new equilibrium is established between the increased rates of mutation and elimination. If in this process the death rate comes to exceed the birth rate, the population will decline and eventually perish. At present we are extremely uncertain about the level of this fatal threshold for a human population. This is one reason why we must be cautious about increasing the total amount of radiation to which the entire population is exposed.

How Much Damage?

Whatever one's point of view, the idea of genetic damage would be clearer if there were some way of expressing it in numbers. Many geneticists, including some on the study committee, feel that an attempt to do this cannot be very meaningful given the present state of knowledge on human genetics. Others, however, think it possible to arrive at rough numerical values that have some significance.

Two approaches to the problem are represented in the report. First, an estimate is made of the amount of radiation, above the natural background, that would cause as many additional mutations in individuals who received it, as now occur spontaneously. This so-called "doubling dose" probably falls somewhere between 30 and 80 roentgens. Second, a figure is given for the total number of mutant genes that would enter the population in the next generation if everyone in the United States received a dose of 10 roentgens to the reproductive glands. The number is estimated to be about five million, with a large range of uncertainty.

Neither the spontaneous mutation rate nor the rate at which radiation induces mutation is known for man. The estimates are arrived at by reasoning from known values in lower forms like fruit flies. Some geneticists are dubious about this step.

Assuming the figures are somewhere in the neighborhood of the true values, what do they mean? At present something like two percent of all U. S. children are born with some noticeable genetic defect. If we were subjected generation after generation to an additional 30 to 80 roentgens, this figure would gradually rise to four percent.

Some geneticists feel that this is the most meaningful way of stating the effects. Others are more interested simply in the total number of mutations produced. They point out that, in the very long run, mutants eliminate themselves only through tragedy. Thus the five million figure represents to them the best measure of the burden which a 10 roentgen exposure would place on society.

In any case, we should not disregard a danger simply because we cannot measure it accurately, nor underestimate it simply because it has aspects which appeal in differing degrees to different persons. Two conclusions seem to be clear and important:

We should vigorously pursue the researches which will in time give us a more precise way of judging all aspects of the risk.

We ought to keep all our expenditures of radiation exposure as low as possible. From the point of view of genetics, they are all bad.

2. Pathology

Passing from the effects of radiation on future generations to its effects on persons directly exposed, we find a considerably simpler situation, so far as the general population is concerned. As has already been mentioned, the inheritance mechanism is far more sensitive to radiation than any other biological system. Therefore, if the general level of exposure is held down to genetically acceptable levels, there would be no noticeable effects on the bodies of the persons exposed. In fact, with two possible exceptions, doses several times as large as the limits recommended by the genetics committee are necessary to produce any obvious damage.

Shortening of Life

The first exception has to do with shortening of life. There is considerable evidence, both from animal experiments and human mortality statistics, that exposure to moderate levels of radiation shortens life expectancy. (Radiologists die five years earlier on the average, than physicians having no known contact with radiation.) This results not only from specific diseases, like cancer and leukemia, that can be caused by radiation, but also from more general, diffuse effects. Radiation appears to lower immunity, damage connective tissue and, in general, to lead to premature aging. Doses up to about 100 roentgens, when spread over years have not been shown to shorten human life. On the other hand, we cannot yet say that there is a minimum amount below which the effect does not take place. If very large numbers of people were exposed to a gradually accumulated dose of 100 roentgens or even less, their life expectancy might well be lowered by a minor, but statistically observable amount.

Internal Radiation

The second possible exception has to do with internal radiation. Until now we have been speaking almost entirely of radiation striking the body from outside. But if radioactive material is swallowed or inhaled, its potential harmfulness is multiplied many times.

At the moment there seems to be only one substance that might represent any threat to the general population in this way. This is strontium of atomic weight 90--one of the radioactive products of nuclear fission. A unique combination of qualities makes this substance especially dangerous. (1) It is one of the more abundant fission products, (2) its half-life is long enough (25 years) to keep it active for many years, yet short enough to make it a strong radiator, (3) it is chemically very similar to calcium and so is taken up and concentrated by bone tissue which has an affinity for calcium, (4) it is known to cause bone tumors in experimental animals, (5) much of it does not fall back to the ground within a short time and a short distance of an atomic explosion. Instead it is carried up into the stratosphere where it spreads over the whole earth and then is deposited gradually, over a period of years.

Already some children have accumulated a measurable amount of radioactive strontium in their bodies. The amount, however, is quite small--a thousandth of what is considered a permissable dose. Presumably, most of it came from the milk of cows which had grazed on contaminated pasturage. It appears, then, that strontium 90 is not a current threat, but if there were any substantial increase in the rate of contamination of the atmosphere, it could become one.

Radiation Disease

Most of the attention of the pathology committee has been devoted to the medical effects of larger amounts of radiation, say 100 roentgens or more. Barring atomic warfare, there is no likelihood that the population in general would ever be subjected to such doses. People working in atomic energy installations, however, might be exposed to large doses through accidents.

We will not go into the detailed medical findings here. In general we may say that the type and severity of pathological effects depend on the amount of radiation received at one time and on the percentage of the total body exposed. It has been learned that shielding a part of the body--any part--reduces the damage in greater proportion than might be expected from the percent of the body mass protected. The reason for this is not yet known.

Very large single doses (say more than 800 roentgens) which strike all or most of the body inevitably cause death. Less than lethal doses produce a variety of effects. The most prominent immediate ones are blood and intestinal disorders; leukemia and cancer are among the chief delayed effects. The skin is very sensitive to radiation. People accidentally exposed to close-in fall-out from weapons tests have developed marked external symptoms, including ulcers and loss of hair, although the total radiation they received was not enough to do serious internal damage. Unless the dose is heavy, skin effects are temporary.

The panel concludes that radiation injury is difficult to treat. "Some success" has been achieved with antibiotics (to prevent secondary infection) and blood transfusions. Certain substances have been discovered which, if taken immediately before receiving radiation, give some protection against its effects, but such treatment is not yet "in any sense practical."

Much more research is needed on the pathological effects of radiation the panel believes. If, for example, it could be discovered why partial shielding gives disproportionate protection, or how the various protective substances work, this might point the way to more effective treatment or more practical protection.

3. Radiation in the Environment

Up to this point we have been concerned with what happens when radiation gets to the "ultimate consumers"--human beings. Despite all the complexities involved, this is in one sense a comparatively straightforward matter. It is assumed, so to speak, that X people receive Y roentgens of radiation and the problem is to predict what happens.

Now we must look into the very tangled problem of how the radiation gets to the people. It is a long way from Eniwetok to Chicago or Bombay. A power station in Oslo or Moscow is a far remove from Johannesburg. Yet all these places are in the same ocean of air; all are surrounded by the interconnecting oceans of water. English grass has been sprinkled with strontium 90 from Nevada. And English cows have eaten it. Plankton in the North Sea has very likely taken up some of the radioactivity being dumped there from a British atomic reactor. Where did the ocean currents then carry this plankton? What fish fed on it? Who ate the fish?

Between the potential sources of man-made radiation and the people of the world is a vast, complex connecting network. It includes the air, the rivers and oceans, and the plant and animal life which form the links in the chain of our food supply. How radiation is distributed--or how its distribution can be controlled--is a problem that calls for the combined efforts of meteorologists, oceanographers, agricultural scientists and experts in the disposal of radioactive wastes.

The Need for Research

The specialists in these fields who make up the committees in the present study have thoroughly reviewed the current state of knowledge. On one thing, all seem agreed: We do not know enough. We must know more about how the winds or the ocean currents move, how plants and animals may concentrate radioactivity and transport it from one place to another. There is still time to find out, but not very much. The amount of man-made radiation that has been put into our surroundings so far is, from almost every point of view, probably negligible. But the testing of megaton weapons continues. In the next couple of decades the atomic power industry will mature and the question of what to do with almost unthinkable quantities of radioactive waste products will be upon us. We had better be ready with the answers.

4. Meteorology

From the standpoint of meteorology, nuclear explosions are more important than controlled reactions in atomic piles, since the former put much more radioactivity into the air. The chief question which the meteorologists must answer is: Once the radioactivity has gone up into the air, when and where will it come down again?

Fall-Out

Fall-out from explosions can be divided into three types: close-in --material that returns to the earth within a few hundred miles of the site of the explosion and within 10 to 20 hours after it has occurred; intermediate--material that comes down in the first few weeks after an explosion; delayed--material that stays in the air for months or years before reaching the ground.

Close-in fall-out is made up of heavier particles in the explosive debris, and is brought down chiefly by gravity. To figure out where it will land, it is necessary to know the type of explosion and to predict the wind patterns in the vicinity for the next 10 to 20 hours. Such predictions are, to put it mildly, not infallible; but, with the help of modern computing aids, they are getting better.

The prediction of close-in fall-out is obviously extremely important in connection with the testing of nuclear explosives, but it does not directly concern the average person.

Intermediate fall-out consists chiefly of particles so small that they would take a very long time to settle out by gravity. They remain in the lower atmosphere for several weeks and are carried many thousands of miles from the point where they originated. It has been discovered that, in the main, they do not simply settle out of the air but are washed out by rain or snow. This means that the material does not come down in a uniform, predictable pattern, but is concentrated in areas where there is precipitation. Hence, under some circumstances a rather limited region might get a disproportionately high share of the intermediate fall-out from an explosion. Following a single Nevada explosion the cities of Albany and Troy in New York received one-tenth of a roentgen of fall-out, or one per cent of the 10 roentgens which the genetics panel has recommended as a maximum for the general population. It is unlikely, of course, that a single region would be so unlucky more than once.

Delayed fall-out is made up of very fine particles that are blown into the stratosphere (higher than 40,000 feet). From the standpoint of its possible effect on humans, the important ingredient of delayed fall-out is strontium 90. The stuff stays in the upper air so long that it is eventually carried over every part of the globe. How long it actually is stored in the stratosphere, and how it returns to the lower atmospheres and thence to the ground is still largely unknown. In fact, the general problem of mixing between upper and lower air layers and of diffusion of material throughout the atmosphere are major questions of meteorology today. This is another of the numerous instances where the answer to radiation questions awaits the solution of more basic scientific problems. It is also true that tracing the course of the radioactive material may be of considerable help in finding the basic solution.

Atmospheric motions are not the only unknown factors in determining fall-out. A good deal is yet to be learned about the anatomy of the explosions--the heights to which various radioactive species are carried, the varying effects of exploding on the ground or at different heights above it, and so on. Also, there is need for improvement in the methods of measuring worldwide fall-out.

Airborne Radioactivity from Industry

At present weapons tests are the chief source of artificial airborne radioactivity. In time, however, the power industry will far outstrip military development work in producing radioactive fission wastes. If not adequately controlled the power program can become a dangerous source of atmospheric radiation.

Some fission products are gases. . If these were released into the air indiscriminately by a worldwide power industry, they would raise radiation levels in the lower atmosphere above what is considered biologically permissable. Obviously, they will have to be contained, or released in limited quantities and at carefully selected times and places.

Major accidents to large power reactors, while very unlikely, are not impossible. If a reactor core vaporized completely, it would spread radioactivity over thousands of square miles unless the vapor were confined. This is why reactors built near populated areas should be housed in sealed buildings strong enough to withstand the pressure developed in the worst nuclear accident.

Tracer Studies

One of the tools which will be used in carrying out the necessary research is radiation itself. Because radioactive substances can be detected in incredibly minute quantities, they make excellent tracers. Medical and biological research have been virtually revolutionized in the last decade by tracer methods. Just as the course of a vital process can be followed with a radioactive isotope and a Geiger counter, so can the courses of winds and tides. Weapons tests themselves have yielded a good deal of information about the motions of the atmosphere, as their radioactive clouds were traced over the earth. More may be learned by releasing specific radioactive materials in the air purely for purposes of meteorological research.

The Atomic Bomb and the Weather

Ever since the first atomic explosion people have wondered about the possible effect of these super-powerful blasts on the weather and climate. The meteorology committee has considered the matter in the light of all the information collected over the past decade. Its conclusion: "No evidence has been found which indicates that the climate has been in any way altered by past atomic and thermonuclear explosions. The amount of study given to the problem is sufficient to indicate that it is unlikely that any test explosions conducted in the number and along lines similar to past tests will have any important effect on the weather. However, this conclusion is based on our present knowledge and the importance of the subject requires continued study."

5. Oceanography and Fisheries

The problems considered by this committee are, of course, very much like the ones in meteorology. A load of radioactive material is put into the ocean at a certain point. Where does it go from there and how long does its journey take?

There is a general tendency, in estimating the effect of dumping foreign matter in the ocean, to assume that it will mix promptly and completely throughout all the waters of the earth. So many tons of waste divided by so many billions of gallons gives some negligible fraction of an ounce per gallon. Nothing could be more misleading, the oceanographers warn.

How Thoroughly Do Ocean Waters Mix?

The current systems of the oceans are varied and complex. They are still very imperfectly charted. But it is known that there are great differences in mixing rates for different regions of the seas. The water in the deeps of the Atlantic has been there for at least 150 years. No one knows yet how it exchanges with surface waters--whether intermittently, at a slow continuous rate, or otherwise. Radioactive wastes deposited on the ocean bottom would have a long time to decay and probably would be diluted with a large volume of deep water before they got into the surface circulation in any amount. This would remove the hazard in the case of short-lived fission products. Oceanographers do not know enough to be able to tell whether long-lived radioactive isotopes, such as strontium, could be safely disposed of in this way.

On the other hand, materials dumped in coastal waters, or upper layers anywhere, will in the course of a few decades at most be carried to all parts of the ocean. There is no place in the sea, the committee cautions, where large amounts of radioactive materials can be introduced into the surface waters without the probability of their eventually appearing in another region where human activities might be endangered.

Plants and Animals Concentrate and Transport Radiation

The dispersal problem is complicated by the fact that the living inhabitants of the ocean as well as the currents may spread materials from one place to another. Furthermore, plants and animals can concentrate certain substances many thousands of times. Water-dwelling creatures "process" untold millions of gallons of sea water, extracting from it the materials they need for their body chemistry. Shellfish concentrate calcium and strontium in their shells. Fish concentrate zinc. If these substances are present in their radioactive forms, the radioactivity will be concentrated at the same time, thus reversing the tendency to more and more dilution.

The committee has considered the question: "Has the atomic energy program as yet resulted in serious damage to marine life?" Its answer is "Probably no.... There is no evidence that any lasting damage has been done to the animal or plant population of the sea or large inland water bodies by the release of radioactive substances" from weapons tests or reactors.

Research Is Needed

The need at present is for intensified research to determine how the waters of the seas actually move, what role marine life will play in the mixing process, what regions are sufficiently isolated so that they can safely take up large quantities of radioactivity.

As the atomic power program grows, "limited, experimental, controlled" sea disposal of radioactive wastes will help determine the safe limits of this method. The committee points out, however, that the operation must be very carefully regulated and evaluated. It recommends that a "national agency with adequate authority, financial support and technical staff regulate and maintain records of such disposal" and that the effects on the sea be thoroughly studied.

The U.S. and other countries with large uninhabited land areas will probably be able to store radioactive wastes until it becomes clear how they can be safely disposed of. However, countries with small land areas and large populations may have to start dumping wastes into the sea from the beginning of their atomic energy programs. The committee reminds us that what happens at any one point in the sea ultimately affects the waters everywhere. Hence it recommends that, as soon as possible, international agencies set up conventions for the disposal of atomic wastes at sea and that research into the problem be carried out on a cooperative, international basis.

The oceanographers plead with "all urgency" that the program of research be stepped up immediately. The problems cannot be attacked quickly or even in many cases directly. 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. They also point out that radioactive materials are powerful tools for studying the biology of fishes and other sea creatures, and thus ultimately for increasing the harvest of the sea.

One of the findings of the committee dramatizes the urgency of oceanographic studies. Radioactive tracers will play an important role in the study of ocean currents and mixing. For the successful use of tracers, the general level of radioactivity must be low enough so that the extra radiation represented by the tracer material can be detected. Such studies can be made today, but this situation will not last very long. "Because of the increasing radioactive contamination of the sea, and the atmosphere," the committee points out, "many of the necessary experiments will only be possible within the next 10 or 20 years. The recommended international scientific effort should be developed on an urgent basis."

6. Agriculture and Food Supplies

This committee has given a good deal of attention to controlled and constructive uses of radiation in agriculture as well as to the harmful effects that would result from general contamination.

It finds that radiation techniques are of great potential value in research. However, it does not believe that they are leading to any drastic, imminent improvement in agricultural production.

Tracer Studies

By incorporating radioactive atoms in the molecules of various substances, it is possible to trace the fate of these substances through complex biochemical reactions. Such studies have already been enormously fruitful in helping us understand essential metabolic processes in plants and animals. They may be expected to be increasingly fruitful as the number and diversity of experiments increase. Tracer methods are useful in many of the problems of agricultural technology as well as in more basic investigations. Thus, radioactive isotopes have been used to study the placement and recovery of phosphorus fertilizers in soils; the efficiency of various methods of applying of insecticides, fungicides and herbicides; the utilization of feed components by animals, etc. Use of tracers in applied research may be expected to expand, and the immediate dividends may be considerable. Further, it is likely that new methods of employing isotopes will be developed; the ingenuity of investigators in this field should not be underestimated.

Mutations

Many researchers are now using radiation to increase the mutation rates in various plants, for the purpose of developing new and improved varieties. Even when they are subjected to radiation, most species have a low mutation rate, and furthermore most mutations are disadvantageous. Hence the investigator must deal with very large numbers. Also, he has been able so far to look only for obvious changes that show up in form or appearance, or for changes which can be recognized by some blanket method such as inoculating all irradiated plants with disease organisms in the hope of finding some that resist infection. It is likely that characteristics at present unrecognized also undergo change. These represent unexplored potentialities for producing better crops.

Radiation has hardly simplified the problems of crop improvement research; on the contrary, it has made them more complex. But it opens many new possibilities. It is not likely that acceptable new varieties can be obtained simply by irradiating existing plants, although this is possible if large enough populations are examined. In general, however, back-crossing and recombination are needed to add the new characteristic to a crop plant acceptable in other respects.

Relatively few new varieties of economic plants developed with radiation, have actually been introduced and widely planted. Those that have, however, attest to the potentialities of the method.

Radiation and Animal Production

Whereas radiation-induced mutations may be of considerable help in developing better crops, they are not so likely to be useful in improving animal breeds. It is not that farm animals are less responsive to radiation than plants, but their size, their cost, and the time required to breed each generation make the necessary experiments less practicable. Probably only poultry and perhaps swine could be handled in sufficiently large numbers. And even here, judging from work with smaller laboratory animals, the chances of improvement seem slim.

Tracer studies on animals are helping to clear up many problems, both in physiology and in applied fields such as the utilization of feed constituents. This type of research is seriously hampered by the expense of disposing of experimental animals. Even where only short half-life isotopes are involved, and at tracer levels, the animals cannot be marketed through the usual outlets, but must be destroyed. The committee believes that essential research is being discouraged. It recommends that procedures and standards be developed which would adequately protect the consumer, but permit the marketing of animals used in radiation experiments.

Contamination

The "natural content" of radioactive elements in foods now consumed by animals and man is not the same as in the pre-atomic age. Though extremely small, the difference is measurable, and inescapable. Fallout from weapons tests has added radioisotopes which were not there before to air, soil and water. The radioactive elements are taken up by crops through the roots and also directly through the leaves. The committee believes that the slowly rising background of radiation caused by weapons testing in peacetime at the present rate is not likely to impair or interfere with food production. However, the levels which might result from atomic warfare, or from mishaps with nuclear power plants in peacetime could have catastrophic effects on agricultural production. In case of severe contamination the material causing most concern would be strontium 90. There appears to be no way of preventing its accumulation in bone tissue. All available foods in heavily contaminated areas might contain significant levels of radiostrontium, perhaps for years.

At present it is not known at what level food becomes unwholesome because of radioactivity. There is not nearly enough information on the long-term biological effects that may follow when men or animals eat radiation-contaminated food. The Committee therefore urgently recommends a long-range research program to investigate these effects. The experiments must be carefully planned to give the kind of realistic information which is needed by agencies charged with protecting the public.

In order to learn about the effects of high levels of radiation on the environment, the committee suggests that ecological studies might be undertaken in areas near weapons test sites. The distribution of radioactivity in the soil at various depths, in the vegetation, in the wildlife, in the streams, and so on, could be investigated. It is possible that land use may influence the accumulated radioactivity in the soil. Forested land, range land, rotation grassland, and plowland, irrigated and non-irrigated, may each present a different situation.

Radiation in Food Processing

Radiation can be used to sterilize certain foods. This process could have a dramatic impact on food technology by reducing the need for refrigeration and prolonging the shelf life of many products. Experiments to date indicate that irradiated foods do not become radioactive and that they will be suitable and safe for consumption by man. As an industrial process, radiation treatment is especially attractive because it can (and should) be carried out after packaging.

Some radiation sterilized foods have been found to develop off-flavors, and changes in odor or texture. The committee believes, however, that with further research means may be found to prevent these undesirable changes.

7. Waste Disposal

The atomic energy program will soon present an unparalleled problem in storage. To keep our general surroundings habitable, enormous quantities of waste products from nuclear fission will have to be tightly contained for very long times.

Past experience gives only a pale intimation of what is to come. To date, comparatively small quantities of wastes have been collected from the various Atomic Energy Commission establishments, which are mostly in isolated regions. Essentially none of the highly radioactive material has been released to the environment, but is stored for the time being in tanks.

How Much Waste?

The committee estimates that by 1965 U. S. reactors will be producing somewhat more than 20 pounds of fission products per day (equivalent in radioactivity to tens of tons of radium). Almost all of this will come from power plants in electric utility networks or naval vessels. By 1980, the accumulated solutions of wastes may amount to 200 million gallons; by 1990, to 600 million; by 2000 to 2.4 billion!

Another dimension of the problem is pointed up by questions of legislation and insurance. What kind of laws, and what type of insurance policies should apply to a company which owns fission products, considering that the materials will retain their radioactivity for, possibly, centuries after the owner has ceased to exist?

Technical Problems

Day-to-day operation of reactors releases some radioactive waste, but methods are already at hand for disposing of it safely. The big problem arises when fuel elements are removed from the reactors and "reprocessed." This is when the fission products are taken out. Some of them, such as cesium 137, are themselves useful, and methods must be developed to separate them economically. Finally the question remains, what to do with the rest?

One unpleasant property ofthe fissionproducts is that they are literally as well as figuratively hot. The more concentrated they are, the hotter their radioactivity makes them. To make storage easier, the wastes should be highly concentrated. But beyond a certain limit they heat up so much that it becomes necessary to cool their containers artificially.

Research thus far has indicated that a number of systems for ultimate disposal of wastes may be feasible, the committee states. Considerably more work is required, however, before any of them is at the point of economic operating reality.

Other aspects also require more investigation. Where should reactors and, especially, fuel processing plants be located? What is the best and safest way to transport large quantities of highly radioactive material? What geophysical and geochemical conditions determine the actual capacity of various regions of the earth to receive radioactive materials?

Accidents

As in every other area of human activity, accidents are bound to happen in the atomic energy program. The problem here is to set up large enough margin of safety so that the accidents that do occur are not catastrophes.

The most serious possibility is that the core of a large reactor might overheat so severely as to vaporize its material completely. If the vapor were released to the air, it would spread disastrous quantities of radioactivity over thousands of square miles. Such an accident is highly unlikely in a properly designed reactor.

Nevertheless, the barest chance of its happening in a highly populated area is intolerable. Until advances in reactor technology substantially reduce potential hazards, reactors located in these regions should be enclosed in sealed buildings, strong enough to withstand the pressures developed by the expanding vapor.

Also, the effects of accidental power-surges on a reactor should be more thoroughly investigated, and better means of controlling them developed.

Accidents in handling and transporting radioactive materials may be quite serious where they happen, but they should not affect a wide area. The contaminated section can always be cleaned up.

It appears that nuclear reactors can be used with reasonable safety to power ships.

Plans for using reactors in locomotives and commercial aircraft are not yet advanced enough so that the consequences of accidents can be foreseen.

Conclusion

It is clear that the safe and rational growth of a nuclear power industry involves more than designing individual plants. The presence of a single large installation will be felt, in various ways, over a wide region. Obviously, it will not do to let nuclear plants spring up *ad lib*, over the earth. The development of atomic energy is a matter for careful, integrated planning. A large part of the information that is needed to make intelligent plans is not yet at hand. There is not much time left to acquire it.

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