THE BIOLOGICAL EFFECTS OF ATOMIC RADIATION

SUMMARY REPORTS

National Academy of Sciences—
National Research Council

THE

BIOLOGICAL EFFECTS OF ATOMIC RADIATION

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From a Study by the

NATIONAL ACADEMY OF SCIENCES

NATIONAL ACADEMY OF SCIENCES — NATIONAL RESEARCH COUNCIL
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FOREWORD

The reports published in this volume summarize the first technical findings and recommendations of six committees established to carry on a continuing study of the biological effects of atomic radiations from the points of view of genetics, pathology, meteorology, oceanography and fisheries, agriculture and food supplies, and the disposal and dispersal of radioactive wastes.

The members of these committees, numbering more than 100, are among the most distinguished scientists in their fields in the United States. They have given generously of their time and talents in making this analysis during the past several months because they are convinced that their fellow citizens should have the facts about the biological effects of atomic radiations based on all existing knowledge available to us. The members of the committees served as individuals, contributing their knowledge and their judgment as scientists and as citizens, not as representatives of the institutions, companies, or Government agencies with which they are associated.

The use of atomic energy is perhaps one of the few major technological developments of the past 50 years in which careful consideration of the relationship of a new technology to the needs and welfare of human beings has kept pace with its development. Almost from the very beginning of the days of the Manhattan Project careful attention has been given to the biological and medical aspects of the subject. By contrast, the automobile revolutionized our pattern of living and working, but we are only now beginning to appreciate the problems of safety, urban congestion, nervous tension, and atmospheric pollution which have accompanied its development. In the same way, the development of the aircraft industry outran our knowledge of how to meet the environmental needs of the human beings it intended to transport through the skies.

The reports now completed vary greatly as to the extent of technical detail they contain. The full reports of each committee, including technical appendices where these have been prepared, will be published at a later date by the National Academy of Sciences. Here only the essential facts, arguments and conclusions as seen today by each Committee are published. As further research provides new facts or further consideration sheds new light on what is now known these conclusions will almost certainly be modified. Moreover as time permits certain specialized aspects of the problem will be studied in more detail by the Committees. The results of these further analyses will be published from time to time as the National Academy of Sciences' study continues.

Douglas M. Whitaker, Vice President of the Rockefeller Institute, has provided coordination and liaison among the study committees with the assistance of Charles I. Campbell of the Academy staff. The study has been greatly assisted by consultations with many authorities in private and Government organizations. Particular mention should be made of the cooperation of the United States Atomic Energy Commission and the Department of Defense. Financial support of the Academy's study of the biological effects of atomic radiations is provided by the Rockefeller Foundation.

Detlev W. Bronk, President
National Academy of Sciences

June 4, 1956

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Report of the

COMMITTEE ON GENETIC EFFECTS OF ATOMIC RADIATION

REPORT OF THE

COMMITTEE ON GENETIC EFFECTS

Foreword

The National Academy of Sciences, with the approval of the top Government authorities, is carrying out an over-all Study of the Biological Effects of Atomic Radiations. One part of that general study is being made by a Genetics Committee, and the present report is a preliminary one from that Committee.

This Genetics Committee has sixteen members, whose names and positions are listed at the beginning of this report. Thirteen of these have been directly and extensively concerned with research in genetics. This number includes specialists on the genetics of lower forms of life, on the genetics of such mammals as mice, on the more mathematical aspects of population genetics, and on human genetics. One member is specially experienced in the general biological effects of radiation, one in radiological physics, and one in pathology.

The problems of the Atomic Age affect every man, woman, and child - in fact, every living thing - in our country, and of course in the whole world as well. Although many of these problems are technical in character, it is nevertheless of importance to our democracy that these matters be as widely understood as possible. Therefore every effort has been made that this report be generally understandable.

This necessitates a certain amount of explanation of technical matters; but this report will use just as few unfamiliar terms as possible, and will define those that are used. It should be understood that many of the statements made in this report would require various qualifications and a lot more detail to attain full technical precision.

The subject is an inherently complicated one, and the reader must be prepared for a certain amount of detailed explanation, some of which is not easy to grasp. It is felt that the subject is important enough so that many citizens will wish to make the effort which is necessary to a careful reading of this report.

The simplifications and abbreviations which have been adopted in this report in order to achieve a generally understandable presentation will undoubtedly be recognized by, and it is hoped will not disturb, the more technical reader. The later sections of the present report will be supplemented by more detail and factual justification if this is later desired by any of the agencies (as for example, the National Committee on Radiation Protection, the Atomic Energy Commission, governmental and industrial groups concerned with radiation hazards, etc.), which have responsibility for the procedures and standards to which our recommendations apply.

This particular report is preliminary for two reasons. First, we wish later to make a fuller report with more technical detail. Second, the situation is changing at such a rate that there should be a continuing series of reports, each bringing the subject up to date.

The National Academy study is not directed toward the problems posed by wartime use of atomic weapons, nor toward the political aspects of atomic power. The study is only indirectly concerned with the social and economic aspects. In fact, the National Academy study, as its title indicates, is concerned with the possible biological hazards due to atomic and other radiations. And the present report, made by the Genetics Committee, is concerned with the genetic aspects of the possible biological hazards. As this report is read, it should become progressively clearer what these genetic aspects are.

I) What Are We Worried About?

The coming of the Atomic Age has brought both hopes and fears. The hopes center largely around two aspects: the future availability of vast resources of energy; and the benefits to be gained in biology, medicine, agriculture, and other fields through application of the experimental techniques of atomic physics (isotopes, beams of high-energy particles, etc.).

Gains in both of these areas can be of great benefit to mankind. Advances in medicine and agriculture are obviously desirable. The wide availability of power can also be of great benefit, if we use this power wisely. For not only should there be enough power to meet the more obvious and mechanical demands, there should be enough to affect society in much more far-reaching and advantageous ways, so as to reduce world tensions by raising the economic standards of areas with more limited resources.

On the other hand, the Atomic Age also brings fears. The major fear is that of an unspeakably devastating atomic war. Along with this is another fear, minor as compared with total destruction but nevertheless with grave implications. When atomic bombs are tested, radioactive material is formed and released into the atmosphere, to be carried by the winds and eventually to settle down at distances which may be very great. Since it does finally settle down it has aptly been named "fall-out."

There has been much concern, and a good deal of rather loose public debate, about this fall-out and its possible dangers.

Are we harming ourselves; and are there genetic effects which will harm our children, and their descendants, through this radioactive dust that has been settling down on all of us? Are things going to be still worse when presently we have a lot of atomic power plants, more laboratories experimenting with atomic fission and fusion, and perhaps more and bigger weapons testing? Are there similar risks, due to other sources of radiation, but brought to our attention by these atomic risks?

II) What Complications Are Met in Reaching a Decision?

Now it is a plain fact, which will be explained in some detail later in this report, that radiations,* penetrating the bodies of human beings, are genetically undesirable. Even very small amounts of radiation unquestionably have the power to injure the hereditary materials. Ought we take steps at once to reduce, or at least to limit, the amount of radiation which people receive?

There are two major difficulties that make it very hard to decide what is sensible to do. First, although the science of genetics is as precise and as advanced as any part of biology, it has in general, and particularly in human genetics, not yet advanced far enough so that it is possible to give at this time precise and definite answers to the questions: just how undesirable, how dangerous are the various levels of radiation; just what unfortunate results would occur?

Second, even if the relevant questions concerning radiation genetics could be answered definitively that would be only part of the story. The over-all judgment (how much radiation should we have?) involves a weighing of values and a balance of opposing aims in regard to some of which the techniques of physical and biological science offer little help.

What is involved is not an elimination of all risks, for that is impossible - it is a balance of opposed risks and of different sorts of benefits. And the disturbing and confusing thing is that mankind has to seek to balance the scale, when the risk on neither side is completely visible. The scientists cannot say with exact precision just what biological risks are involved in various levels and sorts of radiation exposure (these considerations being on one pan of the risk-scale); nor can anyone

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*Throughout this report the word "radiation" is not used in its broadest sense, but refers to certain kinds of high-energy radiations which are described in Section V.

precisely evaluate the over-all considerations of national economic strength, of defense, and of international relations (all on the other pan of the scale).

III) Must We Then Move Entirely in the Dark?

Does this mean that geneticists have, at the moment, nothing useful to say on this grave subject? Fortunately, this is not the case. We do know something, though not nearly enough to give definite answers to a great many important questions. There is a considerable margin of uncertainty about much of this, and as a result, there are naturally some differences of opinion among geneticists themselves as to exact numerical values, although no disagreement as to fundamental conclusions.

Many people, moreover, suppose science to be definite - open or shut. Things are supposed to be so or not so. And therefore some persons may, quite mistakenly, conclude that geneticists are unscientific because they do not completely agree on all details.

In relatively simple fields, where both theory and experiment have progressed far, a comforting kind of precision does often obtain. But it is characteristic of the present state of human radiation genetics that one must carefully and painstakingly note a lot of qualifications, of special and sometimes very technical conditions, of cautious reservations. The public should recognize that the attitudes and statements of geneticists about this problem of radiation damage have resulted from deep concern and from attempts to exercise due caution in a situation that is in essence complicated and is of such great social importance.

It is not surprising that our knowledge of genetics - and especially human radiation genetics - is so fragmentary. What goes on inside cells and the effects of radiations on these processes are extremely complicated and subtle problems. To attack them successfully requires a tremendous lot of time; for the inherent variability of certain of these effects is such that to establish something with certainty one must do not one experiment but many thousands of individual tests and observations. To attack these problems also requires a high degree of special skill - and perhaps most of all, imaginative ideas which can be tested.

Single-celled organisms, as well as fruit flies and corn plants, have been specially rewarding objects of genetic study. In evolutionary terms, however, insects and plants are clearly a long way from man, and we are really just beginning to get genetic information about the effects of radiation on some of the lower mammals, such as mice. Even so, several matters of profound importance have already become clear: bacteria or fruit fly, mouse or man, the chemical nature of the hereditary material is universally the same; the main pattern of hereditary transmission of traits is the same for all forms of life reproducing sexually; and the nature of the effects of high-energy radiations upon the genetic material is likewise universally the same in principle. Hence, when it comes to human genetics, where the impossibilities of ordinary scientific experimentation are clear and only a tantalizing start has been made, we can at least feel certain of the general nature of the effects, and need only to discover ways in which to measure them precisely.

IV) How Could We Reduce Radiation Risk?

The major ways to reduce our present and future exposure to radiations would be: a) to reduce medical and other use of Xrays as much as is feasible; b) to set and to observe regulations for the proper construction and the safe operation of nuclear power plants and for the methods used to dispose of their radioactive wastes as well as the methods used in mining and processing the fissionable material; c) to reduce the testing of atomic weapons and hence to reduce radioactive fall-out; d) to place limits on the human exposures involved in certain aspects of experimentation in atomic and nuclear physics.

To carry out the steps just mentioned would, in greater or lesser degree for the various items, reduce radiation risks. Progress with regard to step a) can doubtless be achieved, although to go too far in reducing the medical use of Xrays would of course lead to the risk of poorer diagnosis and less effective treatment of disease. But to carry out steps b), c), and d) would subject us to a different set of risks. We might thereby impede progress in the nuclear field. We might seriously weaken our country's position in the world. We might deny future generations some of the possible benefits of nuclear power and of other atomic discoveries.

V) Radioactive Material and Radiations

Now that the problem has been posed, and now that we are warned somewhat about the difficulties, we must begin to consider some of the more technical issues involved. What is radioactive material, what are radiations, and what biological effects do they have?

By radioactive material is meant those naturally occurring substances such as radium, or those man-produced atoms resulting from atomic experiments, which are inherently unstable. Instead of remaining unchanged like ordinary atoms of familiar substances such as oxygen, gold, etc., the atoms of these radioactive substances act like alarm clocks set by mischievous gremlins for unknown times. Unpredictably (at least in individual instances, but predictably for the average behavior of a large number) these atomic alarm clocks "go off"; that is to say, they disintegrate.

When radioactive material disintegrates it emits, along with other less penetrating and hence less significant rays, certain high-energy rays known as gamma rays. Some of these rays are entirely similar to a beam of light, except for the important distinction that they readily penetrate human tissue which is nearly opaque to ordinary light. Also the energy of these rays is much higher than that of light, and this enables them to produce chemical and biological changes in the tissue they traverse. Rays of this sort, which transport energy from one point in space to some other point, are in general referred to as radiations. We also class as radiations beams of minute particles travelling at high speeds - such as electrons or neutrons which when they hit matter produce effects like those of the radiation mentioned.

As indicated above, gamma rays are emitted by naturally occurring radioactive substances, such as radium. They are also emitted by the radioactive materials which are produced in the nuclear fission which occurs in atomic weapons testing, in nuclear power installations, and in various sorts of experimental installations. These same rays, in dilute amounts, impinge on and penetrate all of us all the time. For radioactive material is, as an inevitable and hence normal procedure, built into the soil, rocks, plants, etc., and for that matter is also built into our own bodies. Similarly, such material exists on the luminous dials of our watches and clocks. The familiar Xrays of the hospitals and tuberculosis clinics, and in the offices of dermatologists and dentists, have properties of penetration and energy which are similar to gamma rays.

Throughout this report, the word "radiation" refers primarily to gamma rays and/or xrays, sometimes to other sorts of radiations as will be more particularly mentioned later.

Everyone knows what a pound of beefsteak is, or a yard of cloth. We do not have that sort of familiarity with amounts, or units, or dosages of radiation. X or gamma radiation is measured in units called roentgens (abbreviated r; for example, "a dose of 3r"). Dental Xrays involve a dose (to the reproductive organs or gonads, that being the important matter from the point of view of genetics) of about 0.005 r; and a general fluoroscopic examination may involve a dose of 2r or even more.

VI) Some Basic Facts About Genetics

Before we ask what effect radiations have on genetic processes, we must review a little basic information about genetics itself.

Every cell of a person's body contains a great collection, passed down from the parents, the parents' parents, and so on back, of diverse hereditary units called genes. These genes singly and in combination control our inherited characteristics.

These genes, as was just stated, exist in every cell of the body. But from the genetic point of view the ordinary "body cells," which make up the body as a whole, are not comparably as important as the "germ cells" which exist in the reproductive organs, and which play the essential roles in the production of children.

The genes are strung together, single-file, to form tiny threads of genetic material called chromosomes, which are visible under a microscope. These chromosomes, in ordinary body cells, customarily exist as similar but not identical pairs. Human body cells normally contain 48 chromosomes, these constituting two similar but not identical sets of 24 chromosomes each. One of these sets of 24 chromosomes was inherited from the mother, for the egg cell carries a set of 24 chromosomes; and the other set of 24 chromosomes was inherited from the father, for the sperm cell also carries a set of 24.

All the genes that a person starts out with when the original egg cell is fertilized are in general kept unchanged as the cells divide and the person's body is elaborated and maintained. The process by which the dividing cells duplicate the genes may not always produce perfect copies, but it does so in general. But genes do nevertheless essentially change. They are changed by certain agents, notably by heat, by some chemicals, and by radiation. It is with the last of these three agents of gene change that we are concerned in this report.

When a gene becomes permanently altered, we say it mutates. The gene in its altered form is then duplicated in each subsequent cell division. If the mutant gene is in an ordinary body cell, then it is merely passed along to other body cells; but the mutant gene, under these circumstances, is not passed on to progeny, and the effect of the mutant gene is limited to the person in whom the mutation occurred.

However, it cannot safely be assumed that the effect is a negligible one on the person in whom the mutation occurred, nor can it properly be said that this effect is nongenetic, even though passage to offspring is not involved. For various kinds of cellular abnormalities are known to be perpetuated within an individual through body-cell divisions; so these effects are genetic in the broad sense.

What is involved here is not only mutant genes, but also larger scale disruption of the genetic material, such as breakage of chromosomes.

The quantitative relations are not yet clear, but it is established that certain malignancies such as leukemia, and certain other cellular abnormalities can be induced by ionizing radiations. There is also some evidence that effects of this sort measurably reduce the life expectancy of the individual receiving the radiation. These risks have genetic aspects and therefore should receive mention in this report. Indeed these direct risks to the individuals exposed may well constitute another adequate genetic reason for limiting radiation exposures to the lowest practicable levels.

To return to a consideration of the risks which are passed on to progeny, the mutant gene may exist in a sperm or an egg cell as a result of a mutation having occurred either in that cell or at some earlier cell stage. In this case, a child resulting from this sperm or egg will inherit the mutant gene.

If we were to take the two chromosomes of a similar pair, stretch them out straight, and put them alongside each other, then each gene of one would be opposite a corresponding gene in the other. Thus the genes exist in pairs, as do the chromosomes. The two members of each pair of genes are not always identically the same. That is, in fact, why we call the chromosome pairs similar rather than identical. The two genes of a corresponding pair play similar roles, in that they both affect or help to determine the same characteristic of the whole organism. But one of the two may have a somewhat different, or a much more powerful effect than the other.

Thus of a certain pair of genes, both might be concerned with hair color. If both genes of this hair-color pair are the sort which favor red hair, then the person has red hair. If both genes are the sort which favor non-red hair (black, brown, or blond) then the person has non-red hair. But suppose that, of this pair of hair-color genes, one favors red hair and the other non-red hair. What happens then?

The answer (husbands and wives will understand this) is that one of the two usually dominates the situation and gets its way, although (and again this seems reasonable) the meeker one of the two usually manages to avoid being completely ignored.

Thus with one non-red gene (this being the powerful and dominant one of the two), and one red gene (this being the meeker one), the hair is ordinarily not red, but the red gene may nevertheless produce some effect, a little red showing in the hair so as to make it faintly rusty or tawny in color.*

The powerful type of gene, which gets all or most of its own way in contrast to its companion gene, is very naturally called a dominant gene. The less effective type is called a recessive gene. In this same terminology, non-red hair color is called a dominant characteristic, whereas red hair color is called a recessive characteristic. A recessive characteristic actually fully appears only if both of the relevant genes are of the recessive type. Of great importance for our present study is the fact that mutant genes - genes which have, for example, been changed by radiations - are usually of the recessive type.

It is now easy to see that any organism may have, latent in its genetic constitution, ineffectual or recessive genes that have not had much of a chance to become apparent in its developed external characteristics, since the recessive genes are masked by their dominant companion genes. Yet often, as we have seen, this dominance is incomplete and the recessive gene is able to manifest itself partially.

When the two genes of a pair are alike (both recessive or both dominant) then they are called a homozygous pair; but when one is recessive and the other dominant, then the pair is called heterozygous. Thus a recessive characteristic (like red hair) can be fully expressed only when the corresponding gene pair is homozygous.

VII) Radiations and Genetic Mutations

We are now in a position to indicate why it is that radiations, such as Xrays or gamma rays, can be so serious from the genetic point of view. For although the genes, as described above, normally remain unchanged as they multiply and are passed on from generation to generation, they do very rarely change, or mutate; and radiation, as we have already mentioned, can give rise to such changes or mutations in the genes. The change is presumably an alteration in the complicated chemical nature of the gene, and the energy furnished by the radiation is what produces the chemical change. Mutation ordinarily affects each gene independently;and once changed, an altered gene then persists from generation to generation in its new or mutant form.

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*The accurate and complete genetic story about red hair is more complicated than has been stated here. There are less familiar characteristics - thalassemia and sickle cell anemia for example - which more strictly conform to the simple pattern here described.

Moreover, the mutant genes, in the vast majority of cases, and in all the species so far studied, lead to some kind of harmful effect. In extreme cases the harmful effect is death itself, or loss of the ability to produce offspring, or some other serious abnormality. What in a way is of even greater ultimate importance, since they affect so many more persons, are those cases that involve much smaller handicaps, which might tend to shorten life, reduce number of children, or be otherwise detrimental.

The changed character, due to the mutated gene, seldom appears fully expressed in the first generation of offspring of the person who received the radiation and thus had one of his genes mutated. For these 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, that is to say even when in the heterozygous state, they still have some detrimental effect. This "heterozygous damage" is ordinarily much smaller than the full expression of the mutant when in the homozygous state, and yet there may be a significant shortening of the length of life or reduction of the fertility of the heterozygous carriers of the mutant. And the risk of heterozygous damage applies to many more individuals, indeed to every single descendant who receives the gene.

The relations of genes to ordinary traits (not to the most simply determined biochemical traits) are of course much more complex than the previous paragraph would seem to imply. Such gene-determined traits may vary from person to person, due perhaps to environmental differences, and often may not even appear at all. A single gene usually affects several such characters, and characters are practically always affected by many genes. Also the effect of a gene may depend on what other genes are present, often in a complex way. For example, a mutation tending to increase weight might be harmful to certain persons, but beneficial to others.

Indeed it is likely that a large fraction of the genes that determine normal variability are of this rather ambiguous type that are sometimes deleterious, sometimes not. Mutations within this sort would not necessarily be harmful. Such mutations presumably occur, but geneticists do not know what fraction of all mutations are of this type, for they are not ordinarily detectable. However, the mutations that form the basis of this report are those that are relatively detectable, and these, as mentioned earlier, are almost always harmful.

Individuals bearing harmful mutations are handicapped relative to the rest of the population in the following ways: they tend to have fewer children, or to die earlier. And hence such genes are eventually eliminated - soon if they do great harm, more slowly if only slightly harmful. A mildly deleterious gene may eventually do just as much total damage as a grossly and abruptly harmful one, since the milder mutant persists longer and has a chance to harm more people.

In assessing the harm done to a population by deleterious genes, it is clear that society would ordinarily consider the death of an early embryo to be of much less consequence than that of a child or young adult. Similarly a mutation that decreases the life expectancy by a few months is clearly less to be feared than one that in addition causes its bearer severe pain, unhappiness, or illness throughout his life, Perhaps most obviously tangible are the instances, even though they be relatively uncommon in which a child is born with some tragic handicap of genetic origin.

A discussion of genetic damage necessarily involves, on the one hand, certain tangible and imminent dangers, certain tragedies which might occur to our own children or grandchildren; and on the other hand certain more remote trouble that may be experienced by very large numbers of persons in the far distant future.

No two persons are likely to weigh exactly alike these two sorts of danger. How does one compare the present fact of a seriously handicapped child with the possibility that large numbers of persons may experience much more minor handicaps, a hundred or more generations from now?

There are thoughtful and sensitive persons who think that our present society should try to meet its more immediate problems, and not worry too much about the long-range future. This viewpoint is in some instances supported by the belief that new ways, perhaps unimaginable at the moment, are likely eventually to be found for meeting problems.

There are other thoughtful and conscientious persons who think that we are specifically responsible for guarding, as well as we can now determine, the long future.

Recognizing the inevitability and propriety of both viewpoints, and recognizing that they lead different persons to express their concerns through different examples and with differing emphases, the fact of major importance for this present study is that, travelling by different routes, different geneticists arrive at the same conclusion: Complexities notwithstanding, the genetic damage done, however felt and however measured, is roughly proportional to the total mutation rate.

VIII) Mutant Genes and Evolution

Many will be puzzled about the statement that practically all known mutant genes are harmful. For mutations are a necessary part of the process of evolution. How can a good effect - evolution to higher forms of life - result from mutations practically all of which are harmful?

First of all, it is not mutations which, of themselves, produce evolution, but rather the action of natural selection on whatever combinations of genes occur. Much of evolutionary progress probably depends on changes within the range of normal variability, and thus depends on genes of very small effect, and of the type mentioned in the previous section which are favorable or unfavorable depending on what other genes are present. Thus evolution consists of a complex shifting of frequencies of such genes, accompanied by the continuous process of elimination of detrimental mutations and the occasional incorporation into the population of a favorable mutation.

Nature had to be rather ruthless about this process. Many thousands of unfortunate mutations, with their resulting handicaps, were tolerated, just so long as an advantageous mutation could be utilized, once in a long while, for inching the race up slightly higher to a better adjustment to the existing conditions. The rare creature with an advantageous combination of genes was better fitted to survive and displace his less favored companions, and thus evolution was served, even though there were thousands of tragedies for every success.

The reader may be troubled by a second difficulty. If mutation results in at least some favorable types, and if these are building blocks of evolution, why is an increase in mutation rate regarded as undesirable? Why wouldn't an increase in mutation rate produce a larger total number of the favorable types and so speed up evolution? If the favorable types are normally quite rare, wouldn't it almost seem that increasing the mutation rate would be desirable? The answer to this question lies in the consideration that the bad effects of mutation must be balanced against the good. Some mutation is necessary for evolution, but if the mutation rate is too high, the unfavorable mutations will be so numerous that the species and its future evolution will be handicapped. Under present-day conditions of living and medical care, it seems unlikely that the unfavorable results of mutation are being eliminated nearly as rapidly as was formerly the case. In other words, one of the consequences of the amazing mastery of his environment which man has achieved has been an actual decrease in the severity of natural selection.

Geneticists in fact believe that although favorable mutations are rare compared with unfavorable ones, the human population probably already has, and will continue to have as a result of its present mutation rate and without additional mutations from increased radiation, a large enough total supply of favorable, partially favorable, and potentially favorable mutations. In other words, with our present mutation rate we shall continue to have a degree of genetic variability adequate for further evolution.

IX) What, Then, Can Geneticists Say to Help Resolve Our Problem?

With the background furnished by the preceding discussion, we can now state rather concisely certain main points on which geneticists are in substantial agreement. Some of these points will partially repeat statements already made, but they are included here in order that this section be reasonably complete of itself.

1) Radiations cause mutations.

Mutations affect those hereditary traits which a person passes on to his children and to subsequent generations.

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

A small but not negligible part of this harm would appear in the first generation of the offspring of the person who received the radiation. Most of the harm, however, would 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.

Although many mutations do disturb normal embryonic growth, it is not correct that all, or even that most mutations, commonly result in monstrosities or freaks. In fact, the commonest mutations 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, that is, which must be exceeded before any harmful mutations occur.

4) For every living thing - bacterium, fruit fly, corn plant, mouse, or man - there exist mutations which arise from natural causes (cosmic rays, naturally occurring radiations from radium and similar

substances, and also from heat and certain chemicals). These naturally occurring, and hence unavoidable, mutations are usually called "spontaneous mutations."

Like radiation-induced mutations, nearly all spontaneous mutations with detectable effects are harmful. Hence these mutations tend to eliminate themselves from the population through the handicaps or the tragedies which occur because the persons bearing these mutants are not ideally fitted to survive.

We all carry a supply of these spontaneous mutant genes. The size of this supply represents a balance between the tendency of mutant genes to eliminate themselves, and the tendency of new mutants to be constantly produced through natural causes.

5) Additional radiation (that is, radiation over and above the irreducible minimum due to natural causes) produces additional mutations (over and above the spontaneous mutations). The probable number of additional induced mutations occurring in an individual over a period of time is by and large proportional to the total dose of extra radiation received, over that period, by the reproductive organs where the germ cells are formed and stored. To the best of our present knowledge, if we increase the radiation by X%, the gene mutations caused by radiation will also be increased by X%.

The total dose of radiation is what counts, this statement being based on the fact that the genetic damage done by radiation is cumulative.

A larger amount of radiation produces a larger number of mutations. But within the limits of the radiation doses being considered in this report there is every reason to expect that these additional mutants would be of the same general sort as those produced by the natural background radiation. That is to say, mildly larger doses of radiation would produce more, but not worse, mutants.

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.

What is genetically important to a child is the total radiation dose that child's parents have received from their conception to the conception of the child. Since this report necessarily deals with averages, the significant total dose period should be, at least approximately, the number of years that normally elapses from the conception of a person to the average time at which offspring are conceived. In the United States, based on 1950 data, the average age of fathers at the births of all children is 30.5 years, whereas the average age of both parents is 28.0 years. It therefore seems sensible for us to use the round figure of 30 years, especially since this figure is the one usually chosen to measure a generation. Using this 30-year figure for characterizing the "total reproductive life radiation dose" would have the result that about half of the total offspring would receive the possible effects of a smaller, and about half the possible effects of a larger, radiation dose.

7) The problems of defining and estimating genetic damage are very difficult ones.

There are at least three different aspects which must be considered. The first aspect places emphasis on the risk to the direct offspring and later descendants of those persons who, from occupational hazard or otherwise, receive a radiation dose substantially greater than the average received by the population as a whole.

The second aspect refers to the effect of the average dose on the population as a whole.

The third aspect refers in still broader terms to the possibility that increased and prolonged radiation might so raise the death rate and so lower the birth rate that the population, considered as a whole, would decline and eventually perish. We are at present extremely uncertain as to 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.

These three approaches to the problem of genetic damage involve estimating the damage in successive generations and also the total damage in all generations, due to an increase in the amount of mutation. The relative emphasis one places on these three aspects depends in part on whether one thinks primarily in terms of distress to individual persons, or whether one thinks in terms of the population as a whole. Necessarily involved is the contrast between manifest harm to a few, and less evident but no less unreal harm to many. Also involved is the contrast between a more short-term and a more long-range point of view.

One way of thinking about this problem of genetic damage is to assume that all kinds of mutations on the average produce equivalent damage, whether as a drastic effect on one individual who leaves no descendants because of this damage, or a wider effect on many. Under this view, the total damage is measured by the number of mutations induced by a given increase in radiation, this number to be multiplied in one's mind by the average damage from a typical mutation.

Measuring total damage in terms of the number of mutations does indeed necessarily involve this concept of the average damage from a typical mutation, and some geneticists find this concept difficult and illusive. They would point out that mutations may be grouped in classes that differ, on a subjective scale, many thousand-fold in the amount of damage per mutation. As examples they would cite a mutation which results in very early death of an embryo (which might cause very little social or personal distress), and a mutation which results in severe malformation to a surviving child, (which would cause very great personal distress and which clearly involves a social burden).

Rather than utilizing this concept of the average total damage per mutation, some geneticists prefer to start with a consideration of the tangible damage which occurs now, as a result of the current rate of mutation and get an index of damage by multiplying this by the ratio of the expected new mutation rate to the current one. This procedure, however, admittedly deals with only part of the total damage; so an alternative difficulty faces those who prefer this procedure, namely the difficulty of estimating what part of the total damage they have dealt with.

As an illustration of the first aspect, suppose that ten thousand individuals were exposed to a large dose of radiation, of the order of 200 r. Then perhaps one hundred of the children of these exposed individuals would be substantially handicapped, this being in addition to the number handicapped from other causes. In this case the connection with the radiation exposure could be established by a statistical study.

As an illustration of the second aspect, suppose the whole population of the United States received a small dose of extra radiation, say 1 r. Then there is good reason to think that, among a hundred million children born to these exposed parents, there would be several thousand who would be definitely handicapped because of the mutant genes due to the radiation. But these several thousand handicapped children might be, so to speak, lost in the crowd. Society might be more impressed by the one hundred more obvious cases of the preceding paragraph than by the more hidden several thousand cases of this paragraph.

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 of importance: We should proceed with due caution as regards all agents which cause mutations; and we should vigorously pursue the researches which will in time give us a more precise way of judging all aspects of the risk.

X) Some Remarks About Approximate Estimates

Up to this point of the discussion the conclusions of the geneticist are pretty clear; the mutant genes induced by radiation are generally harmful, and the harm cannot be escaped.

But as yet this report has not furnished much of a basis for converting these conclusions into practical advice. Remembering that we must eventually balance risk against risk, it is obviously desirable to try to learn, as definitely as circumstances permit, the answer to the question: how great would be the genetic harm done by various doses of radiation?

Section XII of this report will respond to this question. But before giving the various replies, there should be some preliminary explanation concerning the nature of the answers given.

Science, and particularly the branch which deals with the physical world about us, has succeeded in giving highly precise answers to many questions. When one talks about the velocity of light he does not need to say that it is something like three hundred thousand kilometers per second: he is justified in saying that it is 299,793 km. per second, and that the final integer is almost certainly not off by more than two units.

But when you ask an experienced surgeon what your chances are of surviving a serious operation, and if he answers "something like nine chances out of ten," then you accept that as a reasonable and helpful estimate. You do not distrust him because he gives you a rough estimate. Indeed you would have good cause to distrust him if he tried to give a highly precise answer.

In other words, there are many situations in which science can give only rough estimates. These estimates can nevertheless be very useful. No one should disdain such an estimate because it is rough, nor should anyone consider such estimates unscientific.

In Section XII there will be stated the results of certain approximate calculations. The theory behind these calculations is on the whole well understood; but it is seldom the case that one knows with much accuracy the numerical values that enter into the calculations. One may, for example, say, "I don't know, in any direct measured sense, how many mutants would result if all the genes in a human fertilized cell received one roentgen of radiation. But using a pretty definitely known value for the mutation rate in certain genes of the mouse; and also knowing fairly well (in this case from experiments with fruit flies) how to pass from the measured rate for a few genes to the rate which probably applies to a germ cell as a whole; and then making the unfortunate but necessary assumption that these mouse and fruit fly figures apply reasonably well to man - using this procedure I come out with estimates for the number of mutants which would be produced in man by a given dose of radiation. Because of the uncertainties, I think it prudent to state not a single final result, but rather a range of result with estimated lower and upper limits. I wish that we had direct experimental evidence which would firm up this estimate. But I don't have to be too apologetic, for a large amount of biological reasoning has been successfully based on this sort of procedure. Man differs widely from lower forms of life in all the obvious, and in many other, respects. But the fundamental processes inside cells tend to be curiously alike, from the simplest creature of a single cell, up to man."

It may turn out that the uncertainties in the quantities which enter the calculation are so great that the resulting uncertainty in the final answer is itself so very broad that the calculation simply does not furnish a useful estimate. But it may also turn out that, despite some considerable uncertainty in the constituent factors, the answer can be stated with a range of uncertainty which is small enough so that the estimate is useful.

It seems necessary to emphasize this matter of approximate estimation, so that no one will improperly conclude that a statement is unreliable because it involves a range of values. On the contrary, such a statement, when made in a situation like the present one, should be viewed as all the more dependable precisely because it does not pretend to an unwarranted accuracy.

XI) How much Radiation Are We Now Receiving?

If we are to talk about how harmful certain radiation doses may be, we should gain some idea of the amount of radiation we are already receiving from various sources.

The Committee will release a report specially devoted to this particular subject, which summarizes in detail all the kinds, sources, and amounts of radiation. In the present report, only that minimum amount of information will be given which is necessary for our current discussion.

Neglecting several minor contributions (all of which will be treated in the longer report), man is at present receiving radiations from the following:

1) Background Radiation

This is the radiation which results from natural causes (cosmic rays, naturally occurring radium, etc.) not under our control. Each person receives on the average a total accumulated dose of about 4.3 roentgens over a 30 year period. At high altitudes this dose is greater, because of the increase of cosmic rays. Thus this background is as high as 5.5 r in some places in the United States.

2) Medical X Rays

According to present estimates, each person in the United States receives, on the average, a total accumulated dose to the gonads which is about 3 roentgens of X-radiation during a 30 year period. Of course, some persons get none at all; others may get a good deal more.

3) Fall-out from Weapons Testing

The Atomic Energy Commission* is doing a technically competent and a socially conscientious job of measuring fall-out: but it does not follow from this that one can answer, with high precision, all questions about the biological risks involved. What they usually measure (which, technically speaking, is a beta-ray activity in air) has to be translated over into what is genetically important (namely, the gamma ray dose to the gonads). The estimation of the latter of these quantities from the former is a pretty complicated business.

Beside those just mentioned, there are certain further uncertainties in the fall-out values. The measurements are necessarily taken far apart, and there is known to be considerable local variation due to meteorological conditions and topography. The radioactive dust,

*Under the Department of Defense other measurements, relating to fall-out, are also being made.

when it settles out of the air, is subject to weathering, as when it is washed off of buildings by the rain and carried to locations where it may affect fewer persons. Also individuals inside houses, or other shelters, will be considerably less exposed than those in the open air.

Thus one cannot expect the figures on fall-out to be very precise ones. We have been informed that the AEC scientists are confident that the actual true dose figures are less than five times their stated estimates, and are also greater than one fifth of these stated estimates.

It should be noted that the figures on fall-out as stated by the Atomic Energy Commission make only a conservative correction for weathering and shelter; and thus their figures, at least in regard to this point, tend to overstate the danger rather than the opposite.

With these understandings, it may be stated that U. S. residents have, on the average, been receiving from fall-out over the past five years a dose which, if weapons testing were continued at the same rate, is estimated to produce a total 30-year dose of about *one tenth of a roentgen;* and since the accuracy involved is probably not better than a factor of five, one could better say that the 30-year dose from weapons testing if maintained at the past level would probably be larger than 0.02 roentgens and *smaller than 0.50 roentgens.*

The rate of fall-out over the past five years has not been uniform. If weapons testing were, in the future, continued at the largest rate which has so far occurred (in 1953 and 1955) then the 30-year fall-out dose would be about twice that stated above. The dose from fall-out is roughly proportional to the number of equal sized weapons exploded in air, so that a doubling of the test rate might be expected to double the fall-out.

The figures just stated are based on all information now available from both the Atomic Energy Commission and the Armed Forces, and have been estimated as part of a study carried out for this Committee by Dr. John S. Laughlin, Chief of the Division of Physics and Biophysics, Sloan-Kettering Institute, and Dr. Ira Pullman, loaned to this study by the Nuclear Development Corporation of America. In their estimation correction has been made for weathering and shelter effects in accordance with the latest experimental data.

4) Atomic Power Plants

As yet the general population has not received radiation from atomic power plants or from the disposal of radioactive wastes. These are future sources of radiation that might become dangerous.

5) Occupational Hazards

The preceding four points apply to everyone. Unless proper precautions are taken, persons who are close to equipment emitting X rays, who are engaged in experimental work in atomic energy, who operate atomic plants, who test weapons, who mine or otherwise handle radioactive material, etc., are subject to the risk of greater radiation exposure during their work.

XII) How Harmful Are Radiation-induced Mutations?

As has already been indicated, there are various ways of estimating genetic harm, various attitudes which can be taken as to what is most serious and significant. But this situation should not be allowed to confuse or conceal the massive fact that, by whatever chain of argument or reasoning, all geneticists come out with the same basic conclusions.

A) Thus the first and unanimous reply to the question posed by the title to this section is simply this: Any radiation is genetically undesirable, since any radiation induces harmful mutations. Further, all presently available scientific information leads to the conclusion that the genetic harm is proportional to the total dose (that is, the total accumulated dose to the reproductive cells from the conception of the parents to the conception of the child). This tells us that a radiation dose of 2X must be presumed to be twice as harmful as a radiation dose of X; but it still doesn't tell us the amount of harm we would be doubling.

B) Second we remember that mankind has for ages been experiencing, as the so-called spontaneous mutations, a certain rate of (generally harmful) mutations due to natural and uncontrolled causes (cosmic rays, heat, chemicals, etc.). It is not entirely unnatural to think of this burden of mutations as a sort of "normal" burden on society*. Therefore it seems to be illuminating to ask: how much additional "man-made" radiation will it take before this "natural" amount of genetic mutation (to which we are at least in some senses adjusted) will be doubled?

The calculations which lead to an estimate of this "doubling dose" necessarily involve the rates of both spontaneous and radiation-induced mutations in man. Neither of these rates has been directly measured; and the best one can do is to use the excellent information on such lower forms as fruit flies, the emerging information for mice, the few sparse

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*There is some basis for hoping that we may eventually be able to control at least a part of both spontaneous and radiation-induced mutations.

data we have for man - and then use the kind of biological judgment which has, after all, been so generally successful in interrelating the properties of forms of life which superficially appear so unlike but which turn out to be so remarkably similar in their basic aspects.

In view of the inevitable uncertainties, it is rather surprising that the final estimates, as made by numerous specialists of this Committee and in other countries, do not differ more than they do. The lowest figure which has been responsibly brought forward for the doubling dose is 5 r, and the largest estimates range up to 150 r or even higher. Recent work with mice (which are, after all, mammals) gives some basis for thinking that the doubling dose is not as high as 150 r. The experience in Japan gives some basis for thinking that the doubling dose is larger than 5 r. Indeed it is clear that the doubling dose must be at least as large as the background radiation (which is between 4 and 5 r, over 30 years, in the United States). This, in fact, would be the value of the doubling dose if spontaneous mutations were due to background radiation alone, heat and chemical agents making no contribution.

Thus various arguments reduce the 5-150 r range, and several experienced geneticists have recently made estimates in the narrower range of 30 r to 80 r.

In summary then of this particular point: Each individual, on the average inevitably experiences during his reproductive lifetime a certain number of harmful spontaneous mutations from natural causes. He would experience an additional equal number of harmful mutations if he received a certain dose of radiation during that same period. This is known as the "doubling dose." The actual value of the doubling dose is almost surely more than 5 r and less than 150 r. It may very well be from 30 r to 80 r.

The first portion of this Section XII) said that twice as much radiation gives twice as much harm. This second portion goes a bit further. It says that something like 30 r to 80 r (or at a further extreme, 5 r to 150 r) of extra radiation dose would do mankind twice the harm it is now experiencing from spontaneous mutations.

C) The two preceding portions of this Section are clearly not really satisfying. They do indicate in quantitative terms how increases in radiation increase the harm. But anyone still wants to know in more specific terms, if possible, how serious is this harm that we may be doubling. If city traffic increases until the risk of crossing the street is doubled, then we will presumably still cross the street; for the risk per crossing is, after all, a very small one. If highway traffic increases until the risk in taking a thousand-mile drive is doubled, then many persons might well hesitate, for the risk is now unpleasantly high.

And this is the point at which it becomes most clearly evident that different geneticists find meaningful rather different approaches to the problem of genetic damage.

As has been stated previously, from one point of view the best index of genetic damage is the totality of tangible genetic defects of living individuals - say such things as mental defects, epilepsy, congenital malformations, neuromuscular defects, hematological and endocrine defects, defects in vision or hearing, cutaneous and skeletal defects, or defects in the gastro-intestinal or genitourinary tracts. Roughly 4-5% of all live births in the United States have defects of this sort; and of all of these, perhaps about half - or 2% of the total live births - have simple genetic origin and appear prior to sexual maturity.

If mankind were subjected to a "doubling dose" of radiation, then the present level of 2% of such genetic defects would rise, and would eventually be doubled. More explicitly, consider the next one hundred million births in the United States. This is about the number of children that will, in the future, be born to the presently alive population of the United States. Of these 100, 000, 000 children, something like 2, 000, 000 will experience genetic defects of the sort listed, these resulting from the deleterious "spontaneous" mutant genes which have been induced by natural causes excluding man-made radiation. If we were to be subjected, generation after generation, to an additional doubling dose of man-made radiation, then this present tragic figure of 2, 000, 000 would gradually increase by 2, 000, 000 more cases, up to an eventual new total of 4, 000, 000. It would, to be sure, take a very long time to reach this equilibrium double value. Perhaps 10% of the increase, or 200, 000 new instances of tangible inherited defect, would occur in the first generation.

Since at various places this report considers a radiation dose of 10 r, it may be useful to state the tangible inherited defects from a dose of that size. A dose of 10 r would, on the above basis, give rise to some 50, 000 new instances of tangible inherited defects in the first generation, and about 500, 000 per generation ultimately, assuming of course an indefinite continuation of the 10 r increased rate and also assuming a stationary population.

These figures by no means measure all of the genetic damage that would result from a doubling dose; but they do make tangible and impressive the fact that a doubling dose of radiation would cause real personal and social distress.

D) There is another way of looking at this problem of genetic damage, and that consists of trying to make some useful sort of really long-term, fully complete estimate. This consists of estimating the total number of mutant genes which would be induced in the whole present population of the United States and passed on to the next appearing 100,000,000 children, were this whole population to receive a certain total radiation dose to the gonads. In this instance we will use a dose of 10 r, since a dose of that magnitude appears later in this report in the recommendations. Having estimated this total number of transmitted mutants induced by a dose of 10 r, one then can only say, when he wishes to translate this over into harm or damage, that each one of these mutants must eventually be extinguished out of the population through tragedy. This statement does, of course, not hold in the detailed sense that one thinks of tracing each individual mutant gene until the line which bears and transmits it is overcome by the accumulating handicaps it imposes. The statement holds only in a statistical sense. Some lines of mutant genes will die out merely through normal chance procedures of inheritance. Others will multiply through these same chance procedures. But these normal chance effects cancel out; and the statistical extinction of the mutant genes is accomplished only through tragedy.

Concerning these estimates of total number of mutants, three things should be said. First, they are clearly not really satisfactory to any genetecist. Too much has to be assumed, too little is dependably known.

Second, this kind of estimate is not a meaningful one to certain geneticists. Their principal reservation is doubtless a feeling that, hard as it is to estimate numbers of mutants, it is much harder still, at the present state of knowledge, to translate this over into a recognizable statement of harm to individual persons. Also they recognize that there is a risk involved in extrapolating from mouse and Drosophila data to the human case.

Various remarks can, however, fairly be made in favor of this estimating attempt. Two largely independent methods lead to about the same results, and this increases one's confidence. Although the extreme ranges of the estimates differ widely, the mean estimate for any one geneticist is not very different from the mean for any other. Even the "guessing" which is involved hardly deserves that name, for it is based on long years of experience.

So that the final thing that should be said is that in spite of all the difficulties and complications and ranges in numerical estimates, the result is nevertheless very sobering.

Six of the geneticists of this committee considered the following problem: suppose the whole population of the United States received one dose of 10 roentgens of radiation to the gonads. What is the estimate of the total number of mutants which would be induced by this radiation dose and passed on to the next total generation of about one hundred million children? Each geneticist calculated what he considered to be the most probable estimate, and then bracketed this by his minimum and maximum estimates. Each thus said, in effect: "I feel reasonably confident that the true value is greater than my minimum estimate and less than my maximum. My best judgment, as stated in a single figure, is what I have labelled the most probable estimate."

The most probable estimates as thus calculated by the six geneticists do not differ widely. They bunch rather closely around the figure 5,000,000. Four of the six estimates are very close to that figure, and the other two differ only by a factor of 2.

These six geneticists concluded, moreover, that the uncertainty in their estimation of the most probable value was about a factor of 10. That is to say, their minimum estimates were about 1/10, and their maximum estimates about 10 times the most probable estimate.

This calculation assumes a stable value for the total population. This calculation is admittedly somewhat complicated and disappointingly vague. It is, to some geneticists, not a very meaningful way of looking at the problem. To others it adds up to something at least reasonably clear, and in any event very serious.

XIII) Fall-out

There has been concern about the possible genetic harm due to the fall-out of radioactive material which results from the testing of atomic weapons. Certain aspects of this problem will be discussed in the reports of the other committees of this study (fall-out on grazing and cropland; fall-out in the sea and possible concentration in marine organisms; the distribution of fall-out material by the winds and in the upper atmosphere; possible pathological damage due to long-lived isotopes built into our bones; etc.). The present comments relate only to the question of genetic damage.

From the point of view of this Committee there are two summary remarks that should be made. First, since any additional radiation is genetically undesirable the fall-out dose is genetically undesirable.

Second, the fall-out dose to date (and its continuing value if it is assumed that the weapons testing program will not be substantially increased) is a small one as compared with the background radiation, or as compared with the average exposure in the United States to medical X rays.

XIV) Recommendations

In light of the considerations which have been reviewed by this Committee, and which have been, at least in major outline, summarized in this report, this Committee has several recommendations.

These recommendations should all be interpreted in the light of the basic fact that any additional radiation is genetically undesirable. Therefore our society should hold additional radiation exposure as low as it possibly can. If certain figures (such as 10 roentgens) occur in a recommendation, it should most emphatically not be assumed that any exposure less than that figure is, so to speak, "all right": nor should it be for a moment assumed that disaster will suddenly descend if one of these figures is exceeded.

In any case in which a figure is stated, it is with the idea: stay just as far under this as you can; do not consider that this is an amount of radiation which is genetically harmless, for there is no such figure other than zero.

Opposing the fact that any further radiation is genetically bad is the practical fact that further radiation, from certain sources at least, is probably inevitable. The factors which argue for an increase in radiation are not genetic, and should obviously be appraised by a group much more representative than this Committee. Thus our recommendations will have to be evaluated by others, who must decide what decisions society should or must make. As geneticists we say: keep the dose as low as you can.

Thus we recommend:

A) That, in view of the fact that total accumulated dose is the genetically important figure, steps be taken to institute a national system of radiation exposure record-keeping, under which there would be maintained for every individual a complete history of his total record of exposure to X rays, and to all other gamma radiation. This will impose minor burdens on all individuals of our society, but it will, as a compensation, be a real protection to them. We are conscious of the fact that this recommendation will not be simple to put into effect.

B) That the medical authorities of this country initiate a vigorous movement to reduce the radiation exposure from X rays to the lowest limit consistent with medical necessity; and in particular that they take steps to assure that proper safeguards always be taken to minimize the radiation dose to the reproductive cells.

C) That for the present it be accepted as a uniform national standard that X-ray installations (medical and nonmedical), power installations, disposal of radioactive wastes, experimental installations, testing of weapons, and all other humanly controllable sources of radiations be so restricted that members of our general population shall not receive from such sources an average of more than 10 roentgens, in addition to background, of ionizing radiation as a total accumulated dose to the reproductive cells from conception to age 30.

D) The previous recommendation should be reconsidered periodically with the view to keeping the reproductive cell dose at the lowest practicable level. If it is feasible to reduce medical exposures, industrial exposures, or both, then the total should be reduced accordingly.

E) That individual persons not receive more than a total accumulated dose to the reproductive cells of 50 roentgens up to age 30 years (by which age, on the average, over half of the children will have been born), and not more than 50 roentgens additional up to age 40 (by which time about nine tenths of their children will have been born.)

F) That every effort be made to assign to tasks involving higher radiation exposures individuals who, for age or other reasons, are unlikely thereafter to have additional offspring. Again it is recognized that such a procedure will introduce complications and difficulties, but this committee is convinced that society should begin to modify its procedures to meet inevitable new conditions.

XV) Concluding Comments

The basic fact is - and no competent persons doubt this - that radiations produce mutations and that mutations are in general harmful. It is difficult, at the present state of knowledge of genetics, to estimate just how much of what kind of harm will appear in each future generation after mutant genes are induced by radiations. Different geneticists prefer differing ways of describing this situation: But they all come out with the unanimous conclusion that the potential danger is great.

This report recommends that the general public of the United States be protected, by whatever controls may prove necessary, from receiving a total reproductive lifetime dose (conception to age 30) of more than 10 roentgens of man-made radiation to the reproductive cells. Of this reasonable (not harmless, mind you, but reasonable) quota of 10 roentgens over and beyond the inevitable background of radiation from natural causes, we are now using on the average some 3 or 4 roentgens for medical X rays. This is roughly the same as the unavoidable dose received from background radiation. It is really very surprising and disturbing to realize that this figure is so large, and clearly it is prudent to examine this situation carefully. It is folly to incur any X ray exposure to the gonads which can be avoided without impairing medical service or progress.

The 10 roentgen recommendation applies in an average sense to the population as a whole. We also include a recommendation concerning the upper limit of exposure that any one individual should receive. These limits would of course apply to persons whose occupations involve radiation exposure, but they are intended as broad and uniform regulations which apply to any and every individual.

The fall-out from weapons testing has, so far, led to considerably less irradiation of the population than have the medical uses - and has therefore been less detrimental. So long as the present level is not increased this will continue to be true; but there remains a proper concern to see to it that the fall-out does not increase to more serious levels.

One important lesson which results from this study is the following: The present state of advance in atomic and nuclear physics on the one hand, and in genetics on the other hand, are seriously out of balance. We badly need to know much more about genetics - about all kinds and all levels of genetics, from the most fundamental research on various lowly forms of life to human radiation genetics. This requires serious contributions of time, of brains, and of money. Although brains and time are more important than money, the latter is also essential; and our society should take prompt steps to see to it that the support of research in genetics is substantially expanded and that it is stabilized.

We ought to keep all of our expenditures of radiation as low as possible. Of the upper limit of 10 roentgens suggested in Recommendation C, we are at present spending about one third for medical Xrays. We are at present spending less - probably under one half a roentgen - for weapons testing. We may find it desirable or even almost obligatory that we spend a certain amount on atomic power plants. But we must watch and guard all our expenditures. From the point of view of genetics, they are all bad.

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Report of the

COMMITTEE ON PATHOLOGIC EFFECTS OF ATOMIC RADIATION

SUMMARY REPORT

of the

COMMITTEE ON PATHOLOGIC EFFECTS

Appreciation of the pathologic effects of radiation on man has required of this Committee and its subcommittees, consideration of voluminous experimental work on animals, as well as such direct data on human beings as are available. When the results of controlled experimental studies are considered in the light of the human data, it is found that the sequence of pathological changes is indeed quite similar in man and in animals, although man has certain definable peculiarities of response.

The human data include:

Results of excessive exposure to X-rays and radium in the early days;

Results of more moderate exposure to different forms of radiation, as experienced by cyclotron workers;

Results of introduction of naturally occurring radioelements into the body, notably radium preparations and thorotrast;

Effects of exposure at Hiroshima and Nagasaki;

Observations on populations irradiated by fallout;

Additional observations from clinical radiotheraphy, use of artificial isotopes in therapy, a very limited number of accidents in atomic energy work, and certain statistical surveys of large groups.

Experimental work covers the whole field and includes studies of acute and chronic effects on many species of animals.

Certain human effects have to be assumed from consideration of experimental knowledge: for example, early effects of high doses to the central nervous system, and results of absorption of most of the artificially produced isotopes, and it is fair to say that the lethal dosage of penetrating radiation for man is less well known than for many other species.

Radiation has been added to the means of production of casualties in warfare. Not only can radiation cause death or immediate or delayed injury by itself, but exposure to it intensifies the seriousness of burns or other injuries. The acute lethal dose for half of a given population is in the range of 400 to 600 r.

Despite the existing gaps in our knowledge, it is abundantly clear that radiation is by far the best understood environmental hazard. The increasing contamination of the atmosphere with potential carcinogens, the widespread use of many new and powerful drugs in medicine and chemical agents in industry, emphasize the need for vigilance over the entire environment. Only with regard to radiation has there been determination to minimize the risk at any cost.

It appears, however, that a fairly clear general picture of human radiation effects can be presented. Members of this group and of its subpanels, while recommending various points of departure for greater consideration and further research, were in no case of the opinion that any sort of "crash program" would be desirable or profitable.

The various means whereby persons may be overexposed to radiation will have a great deal of influence on the over-all effects. For example, the exposures at Hiroshima and Nagasaki and a few exposures in accidents in atomic energy plants, involved radiation to the whole body in which the clinical effects reflected mainly injury to the blood-forming tissues and intestinal tract. These tissues are very sensitive to radiation but have a great power of recovery.

Where, on the other hand, exposure has been suffered at a relatively low level from time to time over a period of years, a variety of injurious effects may be encountered, such as leukemia and skin cancer. Among those who have adhered to present permissible dose levels, none of these effects have been detected.

Shortening of life span may result from exposure to radiation not only as a consequence of damage to a specific tissue, as seen in the development of skin cancer and leukemia, but also as a result of such general factors as lowered immunity, damage to connective tissue, or premature aging. Older members of the populations seem to be more sensitive to this nonspecific damage. The shortening of life correlates roughly with dose of radiation, but has not yet been demonstrated at low doses. The following table indicates life shortening in radiologists, who may well have received doses in the course of their occupation ranging from very slight to about 1000 r.

AVERAGE AGE AT DEATH

Physicians having no known contact with radiation.	65.7 years
Specialists having some exposure to radiation (dermatologists, urologists, etc.)	63.3 years
Radiologists	60.5 years
U.S. population over 25 years of age	65.6 years

Shielding of even a portion of the body from radiation lessens the effect out of proportion to the relative amount of tissue protected. Therapeutic radiation to a single portion usually is much greater than the lethal level of total body radiation.

Radiation may have its prominent effects in particular parts of the body when it is applied locally, and this may take place in two ways. First, an external source may be so handled as to direct its radiation to a particular part; in this way many of the early radiologists suffered acute or chronic injury to the hands, which has also occurred in more recent atomic energy accidents.

In the second instance, a radioactive substance may be taken into the body and deposited where it is a source of constant local irradiation until it is eliminated. Bone disease in radium workers and lung disease in miners of radioactive ores (both leading to cancer as a late development) are well-known examples of this mode of exposure. It is worth noting that the atomic energy industry, through diligence, has apparently avoided exposures leading to this type of injury.

It is thus characteristic of the radiations that their effects may manifest themselves not only immediately, but perhaps only after a long period of intermittent radiation, or may even be long delayed after a single exposure. One of the particular tasks of the panel has been to see all of these effects in a common perspective. They will be discussed here in terms of the effects of radiation on the important organs and tissues of the body, since it is a well known fact that some are more readily injured by radiation than others, and that injury to some has more serious consequences than to others.

Among the more serious effects of radiation are those on the blood, since the vital blood forming organs are particularly sensitive to radiation injury. The white blood cells are decreased in number soon after radiation, and in fatal cases they almost disappear before death. Other acute changes in the blood give rise to disorders in the clotting mechanism and a bleeding tendency, and the formation of antibodies against infections is impaired. These changes lead to acute illness in the second week (perhaps a little later in man), heralded by decrease in the white cells.

In the next few weeks anemias may occur due to deficiencies in red blood cell formation and survival. Those victims living through the first month usually recover, but in certain individuals, or where radiation is continued, there is a further serious breakdown of blood cell formation.

Some late effects of radiation appear as leukemias, which are found to arise a few years after radiation. This disease, relatively rare in man, may show manifold increase in persons subjected to a nearly fatal single dose (Hiroshima data) or in those whose professional work has exposed them to higher than acceptable permissible dose rates.

Effects on the intestinal tract are also critical in the early period. Vomiting and diarrhea occur within a few hours. This is a common complication of X-ray treatment to the abdomen, but is not fatal. It seems to be mediated through the vegetative nervous system and is probably not related to later damage.

Within a few days (usually four or five) after radiation, more serious effects occur. Failure of the cells lining the intestine to replace themselves results in denudation of the surface, with intractable loss of fluid and salts; complicated by ulcerations, spread of infection, and bleeding.

Late effects are seen after heavy radiation therapy, and resemble those seen in some other heavily irradiated tissues: overgrowth of connective tissue (fibrosis) and decrease in the number of functioning epithelial cells. Cancer has occurred in animals given overwhelmingly large doses of isotopes in insoluble form by mouth.

Effects of radiation on skin have been widely observed. On the first day an erythema, resembling that of sunburn, appears but is transitory. A few days later a somewhat more persistent erythema occurs which may be associated with pigmentation. Ulceration may occur in this period after high doses. Much later, atrophic changes are seen, with marked deficiency of the blood supply and intractable ulceration; such a chronically damaged skin is a fertile bed for cancer development. The Marshall Island group, while receiving total body radiation insufficient to produce serious changes, had rather marked secondary skin lesions from direct contact with fallout material. Slight local vascular changes have been observed after two years, but serious after effects are not anticipated. Falling of hair was temporary in these persons; heavy dosages are required to make it permanent. In animals, destruction of the pigment cells causes regrown hair to be white, but such loss of pigment seems not to take place in men under comparable conditions.

Bone: Early radiation effects are not of note, except that retardation of growth of epiphyses of immature bones occurs and may produce serious results in children given local radiation therapy. Late effects are seen in radium poisoning, where we see repeated destruction and repair, culminating in widespread destructive changes in which bone sarcoma is likely to appear.

Lung: Early after large doses we see congestion and increased secretion. Here, again, the late-appearing changes are of greatest importance: fibrosis, and development of cancer, which has been very common in mining areas where large concentrations of radon gas were inhaled.

Thyroid: An early and persistent effect is depression in secretory activity, which is used as the basis of the radioiodine therapy of hyperthyroidism. No serious late local effects of thyroid radiation in adults have been recorded, although some leukemias have followed heavy radioiodine treatment. A small proportion of children treated with X-ray to the upper part of the body, however, develop thyroid cancer later on, suggesting a specially high sensitivity of the child's thyroid.

Eye: The only noteworthy lesion is cataract of the lens, which is a late response. It is much more readily produced by neutrons than by X-rays, therefore, has been most prominently observed in cyclotron workers.

Gonads: A single sublethal radiation dose to a male may result in sterility after two to three weeks, followed by a slow recovery. Chronic treatment results in a gradual reduction in number, motility and viability of sperm. This is the most sensitive indicator of chronic damage so far observed, being measurable in dogs at ten times the permissible dose rate. Larger doses (about equal to the total-body lethal dose) permanently sterilize males and females. Experience with the Marshall Islanders, the exposed Japanese, and certain accident cases indicate that total body doses up to about 40 - 50% of the lethal have no permanent effect on human fertility.

Central Nervous System: Observations in man are quite limited. Very high doses given to animals result in loss of coordination and excitement soon after irradiation. At later stages, various effects are seen which indicate sensitivity of particular cells and areas.

Effects on Embryos: Treatment of embryos at various stages of development may lead to highly specific malformations depending on the exact developmental stage at the time of irradiation. At critical stages, relatively low dosages (those permitting survival of the mother) may cause serious malformations. These changes must be distinguished from genetic mutations, as one is often tempted to call abnormal offspring mutations. The type of malformation discussed here would not perpetuate itself genetically, and would result from radiation during gestation.

It must also be remembered that there are various other agents causing malformations during development, of which German measles is a well-known example.

A few factors influencing sensitivity might be mentioned. Very young or very old animals have increased sensitivity to lethal effects. Growing tissues are generally more readily damaged. States like hibernation delay the appearance of radiation damage but do not prevent it. Moderate stresses seem not to effect sensitivity but severe ones such as burns or exhausting exercise, have a deleterious influence, augmenting sensitivity.

Local radiation in sufficient amount to almost any part of the body may produce cancer, the chance of tumor development being somewhat related to dose. Since the cancer cell is an altered type of a normal tissue cell, it has often been suggested that cancer is a somatic mutation, like a genetic mutation but arising in a tissue cell which perpetuates the character by its growth.

All types of induced and spontaneous tumors appear not to arise at once, but to pass through a series of preliminary stages; and radiation induced tumors take a particularly long time to develop. Radiation induced cancer occurs in the absence of a generally abnormal state of the tissue of origin. Mouse experiments show that shielding of a part of the body will prevent radiation leukemia and that shielding of one ovary will prevent a tumor from developing in the other; and several of the tumors appearing late after irradiation seem to be produced in response to indirect mechanisms. If somatic mutation is a necessary part of the induction of cancer, it would seem to play a minor role.

We have so far considered effects of overdosage of radiation in various forms. The question must necessarily be considered, as to whether much smaller amounts of radiation harmless to individuals, might be deleterious to large populations. Because of the striking difference of germinal and somatic cells the former carrying on from generation to generation injuries received, the Genetics Committee has recommended for large populations permissible dose levels of radiation lower than those which are safe for any one generation. As the permissible dose level which they have hypothesized as desirable for large populations were to be applied there would be no demonstrable somatic effect, although a theoretical minor shortening of life span could not be ruled out.

As regards internal contamination, independent data on Rongelap inhabitants and Japanese fishermen indicate that a considerable proportion of the lethal dose of external radiation was received by individuals who barely exceeded, and only for a short period, the permissible internal burden.

The only situation worth considering in relation to large-scale pathologic effects would then be widespread contamination with Strontium-90, which is a long-lived (half life 10,000 days) readily absorbed, bone-seeking isotope which tends to fall out generally over the earth rather than in accordance with the usual close or intermediate fallout pattern. It has already been found that some young individuals have retained 0.001 microcuries or one-thousandth of the permissible dose. This amount if maintained through life would yield 0.2 rep (equivalent r) to the skeleton.

In developing an unequivocally safe amount, we can recall that a certain degree of radiation exposure has always been with us, even excluding X-rays, in the form of gamma radiation from minerals, cosmic rays, and radioelements normally in the body. These levels vary greatly from one location or altitude to another and are not considered to produce harmful effects.

There seems no reason to hesitate to allow a universal human strontium (very similar chemically to calcium) burden of 1/10 of the permissible, yielding 20 rep in a lifetime, since this dose falls close to the range of values for natural radiation background. Visible changes in the skeleton have been reported only after hundreds of rep were accumulated and tumors only after 1500 or more.

In relation to world-wide contamination, food chains are important. Fallout contaminates plants through ground and leaf deposition; animals eat these plants. Because in fact milk and cheese are human sources of radiostrontium, being high in calcium. Throughout this chain, strontium is discriminated against relative to calcium, which reduces the hazard somewhat. It must be remembered that in regions where soil and water are low in calcium, calcium and strontium will be more readily taken up.

As to therapy of radiation injury: while treatment is difficult, some success has been achieved with antibiotics and properly timed blood transfusions. Shielding of a portion of the body appears to give a degree of protection disproportionately large for the mass shielded. Experiments set up to explain this fact may help in developing a rational treatment. Also, various forms of treatment given immediately before radiation have been devised, but do not appear in any sense practical. Studies of this sort may, however, provide a basis for future discoveries.

Because of the nature of this report, specific recommendations regarding needed research are omitted here, but will be published later when the subcommittee reports and other appendices are published in full.

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OUTLINE OF APPENDICES
(To Be Published Later)

I. Subcommittee on Acute and Long Term Hematological Effects of Atomic Radiation - E.P. Cronkite, Chairman.

Introductory Comments by Chairman

Acute Hematological Response to Single Doses of Penetrating Radiation

Long Term Effects on the Blood of a Single Exposure

Effects of Repeated Low Level Exposure

Usefulness of Hematologic Studies in Control of Radiation Injury

Conclusions

Bibliography, 1940-55

II. Report of Subcommittee on Internal Emitters - A. M. Brues, Chairman.

Statement of the Problem

Fallout Conditions

Acute Toxicity

Chronic Toxicity: Site of Injury

Effects on the Lung

Ruthenium; Cesium; Activation Products

The Alkaline Earths:

- Metabolism
- Toxicity
- Sr^{90} - Radium Comparison
- RBE, Alpha and Beta Rays
- Absorption of Strontium

Radioiodine

Report of the

COMMITTEE ON METEOROLOGICAL ASPECTS OF THE EFFECTS OF ATOMIC RADIATION

SUMMARY REPORT OF THE COMMITTEE ON METEOROLOGICAL ASPECTS OF THE EFFECTS OF ATOMIC RADIATION

CHAPTER I

DEBRIS FROM NUCLEAR TESTS

A. INTRODUCTION

Nuclear weapons produce atomic clouds which rise to heights dependent principally upon the energy released and also on the type of burst (air, surface, underground, etc.). Weapons in the kiloton range leave most of their radioactive debris in the troposphere, while megaton weapons are powerful enough to inject significant quantities of radioactive material into the stratosphere. Once the debris is injected into the atmosphere, it is rapidly spread over the earth by atmospheric processes, and eventually deposited on the surface of the earth, in a complex manner. Among the many problems are included: the way in which debris is mixed and transported by the atmosphere, both vertically and horizontally, the mechanism of removal from the troposphere and deposition on the ground, and the rate of penetration from the stratosphere through the tropopause and into the troposphere for eventual removal.

1. Categories of fallout - The problem of the removal of radioactive debris from the atmosphere and its deposition in the biosphere may be divided into three phases: 1) Early or "close-in" fallout, that which occurs within the first ten to twenty hours following a nuclear explosion; 2) Intermediate fallout, that which occurs during the first weeks following the burst; and, 3) Delayed fallout, the slow removal of small particles which may continue for months and even years, particularly after a high-yield thermonuclear explosion.

The principal mechanisms by which the removal occurs are gravitational settling, scavenging of radioactive particles by falling precipitation, and deposition by diffusion resulting from the ever-present turbulent eddies of the atmosphere. Although all principal mechanisms of removal play a role in each phase of the fallout, the primary emphasis shifts from gravitational influences in the early fallout to precipitation scavenging in the intermediate phase to an as yet poorly understood combination of diffusion and scavenging in the delayed fall-out.

2. Measurements

The most direct measurement of radioactive deposition is that made from the soil since it represents the main natural surface onto which the particles fall. Difficulties arise from the fact that rain may remove some of the activity by runoff or soaking deeper into the ground. As a measure of the true radioactivity on the ground in determining plant or animal intake of strontium 90, for example, soil sampling is obviously the most acceptable solution. But, for an accounting of the amount which has been deposited, the soil analysis may be unsatisfactory if the sampling is performed, at say, yearly or multi-yearly frequency. Soil sampling on a frequent basis may be impractical.

Measurement of radioactivity by use of hand monitoring equipment is standard practice in areas where the radioactive deposition is significantly above normal background. This kind of observation is almost entirely useless outside of the areas of close-in fallout.

For daily, weekly or monthly fallout collections, the New York Operations Office of the Atomic Energy Commission recommends the use of a one-square-foot sheet of gummed film mounted horizontally on a stand three feet above the ground. An extensive, world-wide network of daily gummed film collection at about 250 locations has been operated by the Atomic Energy Commission for several years.

Finally, since there is evidence that much of the radioactivity deposited outside of the close-in area is brought down in precipitation, the collection of whole water samples is a method of obtaining the radioactivity of particles.

Air concentration. - Measurement of air concentration near the earth's surface has been achieved by a variety of sampling procedures. Filtration equipment of many types has been successfully employed, but the efficiency of the filter material for various particle sizes, particularly in the sub-micron range, must be determined before quantitative interpretation of the data can be made.

The fact that the upper atmosphere contains significant atomic debris has been known for several years. Sampling of the upper air by aircraft has been achieved by using the motion of the aircraft to pass air through a filter paper. The British report the presence of fission products at the peak altitude of their aircraft, 48,000 feet. The Japanese have measured the radioactivity by carrying aloft Geiger counters on balloons. By subtracting the cosmic ray counts from the total, the remainder is ascribed to fission products. American scientists do not view this procedure with favor for the low levels of radioactivity found over most of the world.

Instrumentation for the measurement of radioactivity by its effects on the electrical properties of the atmosphere also are of use only in those regions where the fission product concentrations are comparatively high.

B. CLOSE-IN FALLOUT

1. Description - Close-in fallout is the radioactive material from an atomic explosion which is deposited on the ground within a few hundred miles of ground zero, and which is down in some ten to twenty hours.

There is a fundamental difference between the fallout from an atomic device detonated at the ground and the fallout from one detonated so high that the fireball does not touch the ground. In the case of the surface burst, large quantities of surface material are broken up, melted, and even vaporized, and some of this material comes in intimate contact with the radioactive fission products. Then, after the atomic cloud has stopped rising and the violent updrafts associated with the explosion have subsided, the larger and heavier particles start falling back to the ground. The result is an area around ground zero and extending downwind which is covered in a more or less systematic way with radioactive particles.

In the case of an air burst in which the white-hot fireball never reaches the surface, the radioactive fission products never come into close contact with the surface material; they remain as an exceedingly fine aerosol. At first sight this might be thought to be an oversimplification, since there have been many cases in which the fireball never touched the ground, but the surface material was observed to have been sucked up into the rising atomic cloud. Actually, however, in such cases a survey of the area has shown that there has been a negligible amount of radioactive fallout on the ground. Though tons of sand and dust may have been raised by the explosion, they apparently did not become contaminated by fission products.

Experience has shown that an atomic device exploded on the surface distributes about 70-80 percent of its fission products on the ground within a few hundred miles of the burst point. A somewhat larger percentage will take part in the close-in fallout from an underground burst, and a smaller percentage will be scavenged from a near-surface burst or tower shot.

In order to make a quantitative study of the manner in which close-in fallout occurs, one must have a knowledge of the following parameters: wind structure, yield and height of burst, and kind of surface.

As each particle falls, it is carried horizontally by the wind at each level. The time during which it is falling through a given layer is inversely proportional to its rate of fall. Thus its horizontal travel during its entire fall from an initial height can be expressed as a summation of its horizontal travel in each layer. The rates of fall of atomic particles vary with particle size, shape, density, as well as the altitude.

Although no experimental information is available on the effects of precipitation during this initial stage of the atomic cloud, it is evident that significant deposition can occur from this cause. However, the effect would be most marked from smaller yield bombs, since the bulk of the debris from larger bombs rises well beyond the rain-bearing strata.

2. Height and size of the atomic cloud at the time of stabilization - It is evident that the physical size of the atomic cloud will have an effect on the distribution of the close-in fallout. The height to which the debris is carried will determine how far downwind a given particle size will drift, and the horizontal extent will serve to spread the fallout over a larger area.

In the first few seconds following an atomic detonation, the fireball grows rapidly, until the pressure inside the fireball is roughly that of the ambient air. At this point its temperature is still many thousands of degrees higher than that of the atmosphere around it, so it is much less dense, and the buoyancy of the atmosphere forces it to rise. However, it does not necessarily rise like a hot "bubble" or a balloon, but in most cases, it develops a strong toroidal internal circulation and rises in the form of a smoke ring.

As the smoke ring rises, its internal circulation draws air in at the bottom and incorporates this new air into the cloud. The result is a very large growth in the size of the cloud as it rises, due mostly to the entrainment of the air from each level through which it passes.

It is clear that the cloud will gradually cool during its rise, due to radiation, the entrainment of the outside air and adiabatic expansion. When the mean temperature inside the cloud is the same as that of the ambient air at the same level, there will be no further buoyancy and the cloud as a whole will cease rising. However, at this point the kinetic energy of the toroidal circulation may still be considerable. For devices with yields of a few kilotons, the smoke ring circulation breaks up at about the same time that it reaches its point of stabilization, but for devices in the megaton range this toroidal circulation continues to pump air in at the bottom for ten to twenty minutes.

The net result of this pumping action after stabilization is a significant increase in the horizontal size of the atomic cloud, since the air which is drawn in at the bottom is forced out radially. Observations of this effect in the case of megaton devices are hindered by the fact that the structure of the cloud becomes confused.

The atmospheric stability will vary with season and latitude, and this accounts, in part, for the difference between the altitude of a cloud detonated in a tropical atmosphere and one of the same yield in a middle-latitude winter atmosphere. The most noticeable difference between these two regimes if the height of the tropopause.

3. Distribution of radioactivity within the cloud - Since it is difficult to obtain enough samples of the radioactive debris while it is still within the cloud to determine its initial distribution, the most reliable estimates of this distribution have been based on the observed fallout and a reconstruction of what this initial distribution must have been.

It is clear from the observations of the rising cloud that almost all of the lighter debris is carried aloft in the smoke ring cloud. Apparently a certain fraction of particles are large enough to be thrown out of this ring, and these are left behind in the stem. However, in the stem there are violent updrafts for the first few minutes, so all but the very large particles will continue to be carried aloft.

For a surface or near-surface burst, the type of terrain must have a significant influence on the particle size and activity distribution within the cloud.

4. Prediction of close-in fallout - At the outset it would be well to state what use can be made of a prediction of the fallout area from an atomic burst. At the risk of oversimplifying the case, here are some of the pertinent factors:

Wind observations, now almost invariably made with sounding balloons, give winds which are not entirely representative of the winds which will affect the falling atomic debris. This is because winds change with time and place and because wind observations, as all meteorologists recognize, are subject to a certain amount of error. Forecast winds, by the same token, are usually even further in error. A number of studies have been made of this subject. For example, a recent study by the Air Weather Service indicates that mean vector errors in 24-hr forecasts range from about 60 percent of the observed wind at middle altitudes to over 70 percent of the observed wind at 100 mb (about 53, 000 ft.). These mean vector errors correspond to wind errors of 18 to 29 knots. It is perhaps significant that these forecast errors at the higher levels (40, 000 - 55, 000 ft.) are about the same as the root-mean-square deviation of the wind from the mean wind, and at lower levels (about 20, 000 ft.) the 24-hr forecast error is about half that of the normal climatological deviation. If one had to rely on forecasts 24-hrs old, he would be just about as well off if he used climatological data or persistence in computing the fallout.

The mushroom cloud from a multi-megaton device may rise entirely above the normal coverage of our radiosonde and RAWIN network, since it is generally considered impractical to plot and analyze current weather data at levels above 100 mb., or about 53, 000 ft. Thus, unless special efforts are made there will simply be no wind data at all for the winds which will affect the debris during the first part of their fall. The effects of vertical motions in the atmosphere, possibly including currents arising from bomb-produced fires, may also be enough to alter the fallout pattern.

It should be fairly evident from the discussion in the preceeding section that there are still a number of questions concerning close-in fallout about which we are still somewhat uncertain. Any fallout computation, even given perfect information on the wind field, will have a degree of uncertainty as a result of the assumptions on which it is based.

With these factors in mind, it appears unlikely that a weather forecaster, even given the computing aids which he would need to compute a fallout pattern, could on short notice and in a time of emergency give a detailed and reliable forecast of the close-in fallout. He could with a fair degree of assurance delineate the general sectors in which the fallout would be most likely to occur, but he could not tell where a given dose rate contour would lie. If one is dealing with a military situation in which an enemy is dropping atomic bombs, then the forecaster's problem is further complicated by the fact that he would presumably not have accurate knowledge of the height of burst and fission yield of the weapon.

It must be emphasized, however, that the above statements do not necessarily apply to the prediction of the fallout from a test device, where many of the uncertainties mentioned can be removed. It is possible, by the use of a special upper air-sounding network, to obtain wind information over a limited area which is considerably more reliable and current than that obtained from the routine upper air net, and which extend to a greater altitude. Moreover, there is usually no doubt about the yield and burst height of the device during a test. Thus, it is much more likely that an accurate forecast of the fallout pattern can be made under the favorable conditions which exist during a test. Even here, there remains a degree of uncertainty, as witnessed by the fallout which occurred on some inhabited atolls during the 1954 tests in the Pacific --- though this might have been forecast if there had been the refined fallout computing aids which exist today.

Finally, if one does not have to make use of forecast winds at all, but can introduce all the detail of a careful synoptic analysis "after-the-fact", including the time variation of the wind at each level, and compute the fallout on a high-speed computer, it is possible to reproduce the fallout patterns which have occurred from the U. S. surface bursts with considerable accuracy. The radiological monitoring data show a certain amount of spread in the observations because of the detailed effects of terrain and atmospheric turbulence. When the reconstructed pattern or computed fallout patterns are compared with observed values, the minor differences are usually accounted for by small-scale features in the wind structure. Where the winds apparently behave as expected, predictions verify within a factor of two over most of the area. Where they do not, the peak dose rate is often correctly predicted at various distances from ground zero although displaced relative to the observed peaks.

C. INTERMEDIATE FALLOUT

Although gravitational settling continues to play an important role for many days, and the downward diffusion of debris from the atomic cloud as it is moved about by the upper winds also becomes important, the primary removal of debris after the first day or two following a burst occurs in areas of precipitation. As the cloud of debris continues to be diluted by the atmosphere, concentrations decrease and it becomes necessary to collect the fallout and wait until the natural radioactivity has decayed before measurements can be made.

From Nevada test series, it has been found that less than 5% of the total beta radioactivity produced is collected by the gummed film network in the United States. Stewart, Crooks, and Fisher have estimated from observations in the British Isles that about half the radioactive dust in the troposphere from Nevada tests is deposited in approximately 22 days and that 80% of the deposition by rain occurs during the first transit of the cloud over England.

The importance of precipitation in bringing debris to the ground after the first day or so following an atomic explosion is strikingly shown in the average daily activity found on gummed films exposed in the United States during the Teapot Nevada test series in the Spring of 1955. In light rain, on the average, over twice as much activity is collected by the gummed film as compared to dry days and this increase becomes more apparent as the rain gets heavier. Various studies have shown that anywhere from four to more than ten times as much debris is deposited during periods of rain as compared with dry days.

On a few occasions, rain has coincided with the passage of a fresh cloud of debris from a Nevada test, resulting in local increases of background radiation to about 1 mr/hr beyond a few hundred miles from the test site.

In the absence of precipitation, the effects of turbulence as well as gravitational settling are important.

Removal of debris by impaction on natural surfaces, buildings, etc., resulting from the movement of air around these surfaces must be appreciable. Various studies have shown radioactive particles are found on leaves, branches, etc. An experiment conducted at the Naval Research Laboratory with an 80-mesh stainless steel wire screen and with ordinary cheesecloth faced into the wind showed that in the absence of rain as much as 10 to 100 times the activity collected on the horizontal gummed film can be collected on the screen or cloth. In a two-month period during the Teapot series, a total of 50% more activity was collected on the cheesecloth than on a horizontal gummed film of similar size. Studies of the vertical distribution of chloride particles also indicate a depletion near the ground over land areas, presumably a result of impaction on natural surfaces.

D. DELAYED FALLOUT

In contrast to the results from the Nevada tests, measurements of radioactive debris concentrations in the troposphere showed a continued increase over England during the 10-month period following the thermonuclear tests in the Pacific in 1954. Similar increases in ground-level concentrations have also been observed by the Naval Research Laboratory in the United States and elsewhere.

This delayed fallout is a consequence of the extreme heights reached by debris from thermonuclear explosions, more than 80, 000 feet, which results in the storage of large amounts of small particle-size debris in the stratosphere. The existence of such a distribution has been confirmed by aircraft measurements over the British Isles in August and September 1954 and again in early 1955 which show a very large increase in air concentration above about 35, 000 feet. This debris eventually moves through the tropopause into the troposphere, from where it is removed by precipitation scavenging and by deposition.

1. Transport in the stratosphere - The stratospheric levels in question are mainly in a region where relatively sparse synoptic data on the structure or air currents are available. However, they are mainly in a region of hydrostatically stable air and soundings indicate, in general, a relative high degree of steadiness of stratospheric currents.

The winds in the stratosphere seem to have a predominant zonal component. The material injected at a certain locality will spread to other longitudes faster than to other latitudes. Material injected at a certain time in a vertical column may move more rapidly, or even in a different direction, at one level with respect to another. This shearing motion of the large-scale air currents represents a powerful factor for the spreading of an originally localized cloud to all longitudes within a few weeks.

All stratospheric circulation cells undergo more or less marked changes during the course of the seasons. Superimposed on the seasonal trend are day-to-day wind fluctuations caused by migrating or oscillating pressure systems. The present-day knowledge of independent stratospheric pressure systems is very limited. But it can be assumed that the stratosphere reacts, at least partly, to the migrating cyclones and anticyclones of the troposphere. Over periods of several weeks the net effect of the stratospheric wind variability will be similar to a process of large-scale eddy diffusion acting mainly in the horizontal directions.

2. Diffusion in the stratosphere - One may approach the question of vertical diffusion in the stratosphere in three ways: first, using first principles; second, using natural gaseous tracers and third using man-made probes.

a. First principles - If asked for criteria to predict vertical mixing at the ground from meteorologically-observed parameters, one would point, in all likelihood, to three items: vertical temperature gradients, wind speed and wind shear. The greater the temperature stability the less the vertical mixing. It is primarily on this ground that the stratosphere has been viewed as a region of quiescence in comparison with a turbulent troposphere below it.

With regard to wind speed, it seems fairly clear that an absence of horizontal kinetic energy will be associated with little or no vertical motions but, it is not evident that high wind speed necessarily will produce vertical turbulence. In any event, the lower stratosphere has a variety of speeds.

In the Richardson number, which under special conditions predicts the onset of turbulence, it is the shear rather than the wind speed which is significant. There is as large an assortment of wind shears in the stratosphere as in the troposphere, barring the layer adjacent to the jet streams in the troposphere.

One must conclude that on one count - probably the most important - stratospheric vertical mixing should be much smaller than tropospheric and that on the other two scores, it need not be.

b. Gaseous tracers - Ozone is the first such atmosphere property which comes to mind. It has been established that the ozone concentrations below the ozone maximum (about 25 km) are often in excess of the photochemical equilibrium amounts. It appears that the day-to-day variations and much of the seasonal variation of total ozone reflects changes in the non-equilibrium ozone in the "protected" region below the maximum. It is generally accepted that exchange processes transport ozone downwards from the region of ozone maximum. Three types of exchange process have been considered. The first involves large-scale meridional circulations in the stratosphere. There are some reasons for accepting such a meridional circulation involving both hemispheres but the evidence is not very impressive. A second exchange process is turbulent mixing. This is difficult to evaluate because of the lack of information on the magnitude of the mixing coefficient. It does seem, however, that the mixing coefficient required to provide the needed flux of ozone is not unreasonable. The third exchange process may be called "Gross austausch" since it involves the vertical motions associated with travelling cyclones and anticyclones. There is good evidence for this effect in the correlations between total ozone and the pressure field. It also provides a qualitative explanation for the annual variation of total ozone.

With the possible exception of the large-scale meridional circulation, the exchange processes described above will operate to bring ozone into the troposphere where it is destroyed at lower levels by particulate matter. The study and measurement of the ozone exchange should be applicable to the exchange of nuclear weapon debris.

Water vapor probably has no marked sink (due to cloud formations or precipitation) near the tropopause. Thus, changes in the gradient of water vapor mixing ratio should be a clue to the comparative upper tropospheric-lower stratospheric mixing intensities. The use of moisture as a tracer suggests but does not clearly indicate little vertical mixing in the lower stratosphere.

c. Man-made probes - Both parachutes and balloons have been used regularly to measure small-scale vertical motions in the stratosphere and the results generally reveal the stratosphere to have greater vertical motions than the troposphere. Also, aircraft report turbulence in the stratosphere. This evidence for comparatively short period vertical motions is clouded by the question of the role of the platform. The growth of the rising balloon, for example, alters the flow around it which may be the cause for the apparent vertical motions deduced from its ascent rate. Further, as with any measure of vertical motions, the probe does not distinguish between non-dispersive vertical motions like gravity waves, and true diffusing elements.

3. Mixing through the tropopause - In a practical definition the tropopause is the level of minimum temperature of a high-altitude sounding, or the layer of maximum change of vertical lapse rate of temperature when no minimum temperature is encountered. Mean height-latitude cross sections of the atmosphere show that the tropopause is quasi-horizontal only in equatorial and polar regions, at approximately 18 and 9 km, respectively. The break occurs normally between 30 and 60 deg. latitude where the mean tropopause has either a significant slope or lacks uniqueness of definition so that multiple tropopauses are assumed by some authors even for mean conditions. Individual soundings may show considerable day-to-day fluctuations of the tropopause level, in connection with the passage of cyclones and anticyclones. Therefore, the tropopause is far from being a well defined geometrical surface and can hardly be considered an internal boundary which separates two distinct kinds of air masses. Air may move vertically through

the mean tropopause level, or horizontally through the tropopause breaks. However, net radiation and convection processes are assumed to exist which result in a marked tendency towards re-establishment of the tropopause at preferred levels just above the atmospheric layer in which the content of liquid and vaporeous water is significant and condensation-precipitation cycles are dominant.

Four main types of exchange of air, or air properties through the tropopause may be distinguished: (i) small-scale vertical exchange, or vertical eddy diffusion - (ii) medium-scale penetration of tropospheric air into the stratosphere above extremely intense convective cells (heavy squall lines, frequently connected with tornadoes) - (iii) large-scale entrainment of stratospheric air into tropospheric systems such as cyclones, jet streams, hurricanes - and (iv) mean transport by vertical branches of large-scale to world-wide circulation cells.

4. Tropospheric removal - The very small particles which are originally in the stratosphere and reach the troposphere weeks, months and even years after the detonation of a thermonuclear weapon, must eventually be deposited in the biosphere. However, the mechanisms by which these small particles are finally removed from the troposphere are not clear and the data concerning this problem is inconclusive.

Investigations of the rate of removal of natural radioactivity from the lower troposphere, both in the United States and in Germany, indicate that about half the activity is removed in a period of about one or two weeks. However, the particles involved are extremely small (probably less than 0.01) and are concentrated near the ground, so that the results may not be applicable to the fallout problem. On the other hand, Langmuir has shown that the collection efficiency of precipitation for very small droplets (less than 1) is small, but again the results may not be applicable to the fallout problem, where electrostatic and surface tension phenomena are different. Agglomoration between natural cloud elements and radioactive particles is operative for small particles.

Conflicting evidence on the rapidity of tropospheric removal is also found in studies of the actual fallout. Stewart, Crooks and Fisher, in Britain, estimate from indirect reasoning that deposition in rain exceeds dry deposition by a factor of twenty for thermonuclear explosions, a study of gummed film results in the United States does not bear this out - average monthly deposition at 40 monitoring stations during September and October, 1954, shows no correlation with either total rainfall during the month or the number of days with rain at the station. Again, using the British data, it is seen that the specific activity of the lower atmosphere showed a more than fourfold increase during the interval from 10 weeks after the Pacific tests to 50 weeks after if the data is corrected for decay. Similar increases were found by the Naval Research Laboratory. It is hard to reconcile this increase in tropospheric concentration with the rapid cleansing of the troposphere.

E. ANALYSIS OF STRATOSPHERIC STORAGE FROM RADIOSTRONTIUM FALLOUT DATA

1. Statement of the problem - The fission product of greatest interest in terms of long-term hazard from nuclear detonations appears to be Sr^{90}, and estimates of the rate of deposition of this isotope in the biosphere are needed. Unfortunately, our knowledge of the physical mechanisms involved is too meagre to deal with this problem on a theoretical basis. Although it has been established that a considerable amount of debris is injected into the stratosphere and that this debris slowly mixes downward into the troposphere and is eventually deposited on the ground, the average storage times in the stratosphere, and even in the troposphere, are uncertain. Among the many unknowns in attempting a theoretical analysis are the initial distribution in the stratosphere and the physical mechanism of stratospheric removal. Even if the latter were known, we are at present unable to make quantitative estimates of the rates or intensities of these physical processes. However, due to the biological uncertainties in estimating the hazard from Sr^{90}, a precise answer is not needed, and even a gross estimate would be useful.

2. Analysis by W. F. Libby - Dr. W. F. Libby of the Atomic Energy Commission has published an estimate of the stratospheric storage time based on the estimated stratospheric content and on the observed deposition, with little or no reference necessary to the physical mechanisms involved. Essentially, the annual deposition is divided by the amount in the stratosphere, yielding the fractional removal during the year. If the fractional removal rate is assumed constant (i.e., the stratospheric content is assumed to decrease exponentially) the mean residence time of the debris is given by the ratio of the stratospheric content to the deposition.

The basic data used by Dr. Libby are the stratospheric content immediately after the completion of the Castle (Spring 1954) tests in the Pacific and the deposition of Sr^{90} during the following year or so as measured in three ways, a world-wide gummed film fallout network, the Sr^{90} content of Chicago rainfall and air filter measurements at Washington, D. C. From these results, Libby concludes that the mean storage time for debris in the stratosphere is approximately 10 ± 5 years.

3. Conclusion - Stratospheric storage not only serves to delay the fallout of debris, but also to disperse it over the globe, minimizing the chance of locally high concentrations of debris. At present, the amount of Sr^{90} in the stratosphere from nuclear weapon tests is far too small to approach maximum permissible concentration even if it were to be all deposited now. However, if the testing programs of the several countries producing thermonuclear weapons were to intensify, stratospheric storage time may become a critical item in terms of hazard to mankind. For this reason, a continuing program to investigate this phenomenon is needed, including actual measurements of the radioactivity in the stratosphere and improved and more representative methods of observing fallout

CHAPTER II

ATMOSPHERIC RADIOACTIVITY FROM CIVILIAN APPLICATION OF NUCLEAR ENERGY

A. SOURCES OF CONTAMINATION

The hazards of atmospheric contamination from the military uses of atomic energy have tended to overshadow other possible sources of contamination, principally because, to date, relatively insignificant contamination has occurred from non-military sources. Certainly, the near future will see a tremendous increase in the utilization of nuclear energy for peaceful purposes, including the production of electric power, medical, industrial and agricultural applications, and nuclear propulsion of air, sea and land vehicles.

As far as can be seen today, the largest potential use of nuclear energy will be in the production of electric power and the discussion is based on this aspect of the problem, however, other applications could conceivably double the values used in the estimates given here. A consensus of estimates of global power requirements and of the proportion of this energy which will be supplied by nuclear sources indicates that by 1975 there will be a nuclear heat energy production of 10^8 to 10^9 kilowatts and by the year 2000 this will increase to 10^9 to 10^{10} kilowatts.

These rates of production will produce enormous amounts of fission products. However, most of these will be in solid or liquid form at present day processing temperatures and it can be expected that such material will not be intentionally released into the atmosphere.

Of the remaining volatile fission products, storage and "cooling" of the fuel before processing can reduce the activity materially. The two volatile isotopes of most interest are 10-year krypton 85 and 8-day iodine 131. Only the 10-year krypton is sufficiently long lived to be relatively insensitive to the cooling time of the fuel before processing. There are two aspects to the problem of radioactive hazard from these sources, large-scale contamination on a global or hemispheric basis and local or regional contamination in the areas of processing plants.

B. LARGE-SCALE CONTAMINATION

1. Krypton 85 - The long half-life of Kr^{85} results in the accumulation of this isotope in the atmosphere. If by the year 2000 nuclear thermal power has risen to 10^{10} kilowatts, the world inventory of radiokrypton would be of the order of 10^{10} curies. Mixed uniformly through the mass of the troposphere (4×10^{21} grams of air), the resulting sea-level concentrations would be less than 10^{-8} curies/meter^3. Since most of the activity is likely to be released in the middle latitudes of the northern hemisphere, large scale concentrations of 3 to 5 times the global average could be experienced in these latitudes.

No value for the maximum permissible concentration of Kr^{85} is presently available. If, from the chemical and radiological similarity, we assume that it is analogous to radioxenon, then the estimated world-wide concentration in the year 2000 is about two orders of magnitude less than the maximum permissible concentration. However, such comparisons are extremely questionable and it is important that maximum permissible concentration levels be established for Kr^{85}.

2. Iodine 131 - The problem of I^{131} in the atmosphere is largely dependent on the fuel recharging interval and the cooling time. For each combination of fuel cycle and cooling time it is possible to calculate the total amount of I^{131} in the atmosphere. This is an equilibrium value assuming no removal at the source or after release. Total amounts of I^{131} in the atmosphere based on the estimated nuclear energy production in the year 2000 are given in the following table.

Total I^{131} (curies) in the atmosphere
per 10^{10} kilowatts of nuclear energy

Fuel recharging frequency:	Decay time before release: none	10 days	100 days
Once a year	6×10^9	3×10^9	10^6
10 times a year	6×10^{10}	3×10^{10}	10^7
Continuous	2×10^{11}	10^{11}	4×10^7

The present maximum permissible concentration of I^{131} is 3×10^{-9} curies/meter^3. If the I^{131} is mixed with the whole mass of the troposphere, then 10^{10} curies would produce the maximum permissible concentration. However, the assumption of world-wide tropospheric mixing is unwarranted for an isotope with a half-life of 8 days. Assuming the term large-scale contamination in the case of I^{131} can at most involve a 20° or 30° band of latitude in the northern hemisphere, and that vertical mixing may be incomplete, then even for large-scale considerations an atmospheric burden of 10^8 or 10^9 curies of I^{131} may approach the maximum permissible concentration, and appropriate cooling or decontamination measures must be used.

C. LOCAL CONTAMINATION

It is evident that consideration of the average contamination over major portions of the globe cannot approach the hazard to be found in local areas downwind from sources of contamination. Locally, higher concentrations that would exist 10 to 100 miles from fuel processing plants (assuming something of the order of 1% of the world's fuel to be processed at any single site) could add an additional factor of 10 to 100 in the case of Kr^{85} and several thousand in the case of I^{131}. Also, transitory excess concentrations due to unfavorable meteorological conditions could raise local concentration by an additional one to two orders of magnitude.

The above effects are cumulative so that concentrations of I^{131} about 10^4 times the global average could occur regularly near fuel processing plants in the northern temperate latitudes, rising occasionally to 10^5 - 10^6 times the global average during unfavorable meteorological conditions. Deposition by precipitation could increase the possibilities of harmful effects. Further detailed analysis would be required in order to indicate under what conditions the concentrations of krypton, iodine, or other isotopes would exceed permissible limits. In any case, it seems that a combination of reasonably conservative fuel cooling periods, some progress in off-gas cleaning, and a judicious choice of fuel processing locations, is indicated to minimize the adverse effects of unfavorable meteorological conditions. At the larger plants, meteorological scheduling of gas releases may be required. These principles are applied today, and will become increasingly important.

D. ACCIDENTAL RELEASES

There is the possibility, even if remote, that a large high-power reactor or fuel processing facility could be damaged or destroyed by accident and release part or all of the contained fission products to the atmosphere. The results of such an event could well be catastrophic, and extend over great distances. Estimates of areas of damage range upwards of thousands of square miles for very large reactors. By the year 2000 the release of only about 1% of the world-wide Sr^{90} inventory that could then exist, even if mixed uniformly throughout the global troposphere, could produce concentrations on the order of 5×10^{-10} curies m^{-3} or about twice the currently recommended maximum permissible concentration. This same 1%, if deposited on the surface, could seriously contaminate the entire area of the earth. It is more likely, in the event of such a catastrophe, that the activity would remain concentrated in a much smaller area near the source. Still, the operation of any significant fraction of the earth's nuclear reactors without proper safeguards would be of concern to all.

E. CONCLUSIONS

The solution to radioactive air pollution problem is the same as in other air pollution problems, prevention of the escape of pollutants to the atmosphere. Thus, primary consideration must be given to engineering features limiting the escape of hazardous gases either during normal operations or accidents. As additional safety factors meteorological research to locate plants in areas where unexpected releases will do the least damage is desirable. Finally, it should be pointed out that the release of a hazardous substance by any country may affect other countries - particularly in the same latitude belt. International control to establish and maintain high standards of safe plant operation is essential.

CHAPTER III

USE OF RADIOACTIVITY IN ATMOSPHERIC STUDIES

A. NATURAL RADIOACTIVITY

There exist two important sources of naturally occurring radioactivity in the atmosphere: (1) cosmic ray interactions in the stratosphere and (2) the rock and soil of the earth's outer crust. The study of the cosmic ray induced products entails considerable difficulties because of the low level of activity. On the other hand, the radioactive substances which originate in the earth can be detected and measured with relative ease.

Radon and thoron are released as gases in the radioactive decay of radium and thorium which are found in all rock and soil. The concentration of these gases and their distribution in the atmosphere is determined by their half-lives and meteorological conditions. Although it is considered generally that the relative amounts of the various natural activities are dependent on meteorology, very few correlations with specific meteorological parameters have been made, in spite of the fact that measurements have been carried out over a period of many years. At the present time, insufficient data are available to make reliable estimates of the global distribution of radioactivity in the air over land, although it is known that at some distance from large land masses the radioactivity concentration is exceedingly low. Measurements indicate that the amount of radon decreases rapidly with altitude to about one half the surface value at one kilometer.

Radon and thoron and their daughter products would seem to provide an easily detectable tracer for the study of the vertical "Austausch". Ground level measurements indicate that exchange phenomena within even a few feet of the surface have marked effects on the concentration of radioactivity. Such measurements might well be carried on in conjunction with micro-meteorological observations. From consideration of the lifetimes of the radioactive isotopes which are involved, it is obvious that even for relatively low wind velocities, horizontal transport of these radioactivities over distances of several hundred miles is entirely possible. The study of simultaneous variations in concentration over these distances should be valuable if the locations were carefully selected to avoid the effects of terrain. Land to sea measurements should be especially interesting.

Instances of increases in radon concentration coincident with air pollution have been reported. Since atmospheric radioactivity and pollution are strongly affected by the stability of the lower atmosphere this effect is not surprising. For the same reason it is quite possible that a relationship could be established with the tropospheric scattering of electromagnetic radiation.

Experiments have shown that the radon and thoron decay products are attached to submicron particulates. The details of the attachment process are not well understood; for example the relationship between various ionic species or the number and kind of nuclei. These radioactivities exist in the form of a readily detectable submicron aerosol which generally follows the surface wind pattern. These small particles, and incidentally other pollution, appear to be removed from the lower atmosphere in a matter of days, principally through precipitation. Further study of this removal process, carried out at different locations and for a variety of climatological conditions would perhaps shed some light on the scavenging efficiency of precipitation.

The natural radioactivity of precipitation is considerable and is easily measurable. The mechanism for the entrainment of the radioactive particles in rain droplets is not certain. From theoretical considerations, the probability for attachment of these very small particles in rain is quite low. It has been suggested that the radioactive ions could themselves act as condensation nuclei. On the other hand, there is the possibility that clouds of charged radioactive particles could act as a sort of "trigger" for electrical phenomena leading to cloud electrification and precipitation. Experimentally, the difficulties of working with large volumes of rainwater are partially offset by the large activities encountered. The actual air volume swept out by precipitation is very great and it would seem that there are possibilities for tracing air masses by using natural radioactivity.

Traditionally atmospheric radioactivity has been associated with atmospheric electricity and might well supplement studies in this field. The radon and thoron decay products are charged and can be collected by electrical means. They are estimated to cause about one half of the ionization in the lower atmosphere. Certain of the theories of atmospheric and cloud electrification are quite sensitive to changes in the ion concentration. Since large changes in the radioactivity concentration are the rule, further studies carried out in conjunction with atmospheric electrical measurements should be valuable.

The most extensively studied of the cosmic ray induced isotopes found in the atmosphere have been C^{14}, H^3 and Be^7. Probably both short term increases in fossil CO_2 from industrial sources and the long term global distribution could be detected using sensitive techniques. H^3 is present in the air principally in the form of tritiated water and will probably find its most useful applications to hydrology, although more extensive sampling of precipitation is no doubt desirable. Because of its relatively short half-life, Be^7 may be of very great importance in the study of the rate of mixing between the stratosphere and troposphere. Unfortunately, there is a great lack of experimental information suitable for correlation with meteorological phenomena.

B. DEBRIS FROM WEAPONS TESTS

The debris injected into the atmosphere from the testing of nuclear weapons can provide a useful tool for investigating atmosphere phenomena. However, two basic limitations on the usefulness of the approach must be recognized:

1. The source strength and distribution in space is largely unknown. Such important information as the distribution of

particles with altitude, the exact configuration of the stabilized cloud, the relation of particle size to activity, the fractionation of elements within the cloud, etc., is not available.

2. Sampling techniques are imperfect. Air concentration measurements are difficult because of the low concentrations and small particle sizes involved. Ground collections result from either deposition of the particles themselves or by precipitation scavenging.

Using the gummed paper collection system described in Chapter I, it has been possible to obtain certain valuable meteorological information on such items as: a measure of the cross-equatorial transport and some feature of the general circulation from U. S. Pacific tests, scavenging by the upper portions of rain clouds of the particulate fission products, an estimate of rapidity of the removal of particulates from the troposphere, an estimate of the rate of transport from the stratosphere to troposphere.

Using aircraft sampling procedure, it has been possible to obtain estimates of the rate of laterial spread of an atmospheric contaminant and verifications of meteorological trajectories.

By following the Tritium released by the CASTLE series of weapons tests it has been possible to estimate the removal time for atmospheric water molecules.

It is likely that the potential of even the existing unclassified information on radioactivity released by weapons tests has not been exhausted. This potential would be enhanced by disclosure of additional information on weapons, debris measurements, and source strengths. For example, the weapons tests offer an opportunity to determine storage and transit time parameters for surface water sheds of almost any size. By comparing the amount and level of radioactivity in rainfall and runoff as a function of time following a weapons test, it would be possible to measure those parameters which are vital to studies of ground water, river runoff, and flood forecasting.

C. ARTIFICIALLY INTRODUCED RADIOACTIVE TRACERS

Artificially introduced radioactive tracers can serve meteorology in at least three fields: first, through the delineation of the air flow and rates of diffusion; second, in hydrometeorology, including studies of condensation, precipitation, evaporation and hydrology; and third, in atmospheric electricity.

As a tracer of air motions, radioactive substances are in competition with fluorescent dye particles, sulfur dioxide and other non-radioactive substances. Their advantages lie in the possibility of being able to treat large-scale atmospheric phenomena which otherwise require too large amounts of source material, in being able to utilize tracers which partake in the particular process under investigation and, in certain cases, in our ability to detect the presence of the tracer instantaneously in the field. In any specific experiment it will be necessary to weigh economic, safety and scientific factors in the use of radioactive tracers over non-radioactive tracers.

Regions in which it would be highly desirable to further knowledge concerning air trajectories are in the neighborhood of jet streams, in cols, in hurricanes to measure both the three dimensional airflow and define the air comprising the eye, and in the Antarctic. In the field of diffusion, the use of radioactive tracer material can further knowledge of diffusion near the ground for air pollution studies, etc., and of diffusion in the stratosphere and tropospheric and stratospheric mixing.

The radioactive tracer material which appears to be most promising for the above meteorological studies is tritium. Tritiated water would be washed out, thus making for additional complications. Tritium in the form of ordinary hydrogen is acceptable although costs of analysis of the sample might be high. For the large-scale experiment to establish the tropospheric-stratospheric exchange tritiated methane has been suggested. Tritium has the advantageous properties of emitting a weak beta particle, of being available without difficulty, and of having a reasonably long half-life.

Water molecules are readily marked by tritium so that in any experiment in which the travel of water vapour is desired it becomes feasible to introduce tritiated water as a tracer. If sufficient amounts of tritium were available, a large-scale experiment to study the hydrologic cycle could be devised. Even on smaller scales, tritiated water could be used to study such features as the evaporation from a ponded lake, water sources for dew, contributions of local transportation or evaporation from local bodies of water to precipitation elements, etc.

Activation analysis techniques extend the possibilities for studying very small particles (such as sodium chloride) that play an important role in condensation and ice formation. Radiosilver can be introduced in a preparation of silver iodide to be able to determine the presence of silver iodide in the precipitation which was alleged to be stimulated by it. By releasing another tracer which would be scavenged with equal efficiency by precipitation it might be able to determine whether the silver iodide has played a role in the formation of the precipitation.

Finally, the ionizing properties of radioactive substances can be used to make local changes in the electrical fields of the atmosphere, to determine if such changes affect weather processes.

CHAPTER IV

THE EFFECT OF ATOMIC EXPLOSIONS ON WEATHER

A. INTRODUCTION

From the beginning of time, man has looked beyond the field of meteorology in the hope of finding some explanation for the vagaries of weather. Many inventions of man - gunpowder, radio, airplanes, and television - have been blamed for changes in weather and climate. It is only natural that atomic and thermonuclear explosions, being among the most dramatic achievements of mankind, would come in for their share of the blame.

There seems to have been an increase in unusual and undesirable weather in the past decade. When submitted to rigorous statistical tests, these apparent abnormalities do not exceed the limits that can be expected by chance and are consistent with accepted meteorological principles involving large-scale (hemispheric) weather patterns which could not be directly affected by the explosions. The failure to detect statistically significant changes in the weather during the first ten years of the atomic age is no proof that physically significant changes have not been produced by the explosions, but it does show that a careful physical analysis of the effects of atomic and thermonuclear explosions on the atmosphere must be made.

The energy of even a thermonuclear explosion is small when compared to most large-scale weather processes. Moreover, it is known that much of this energy is expended in ways that cannot directly affect the atmosphere. Even the fraction of the energy which is directly added to the atmosphere is added in a rather inefficient manner from the standpoint of affecting the weather. Meteorologists and others acquainted with the problem are readily willing to dismiss the possibility that the energy released by the explosions can have any important direct effect on the weather processes. However, there remains the possibility that the explosion will serve as a trigger mechanism to divert some much larger natural store of energy from the path it would otherwise have followed.

Three general means by which this might be accomplished have been considered:

1. The debris thrown into the air by the explosion may have some catalytic effect on the behaviour of clouds and thereby change the regime of cloudiness or precipitation over wide areas.

2. The radioactive nature of the debris will change the electrical conductivity of the air, and this may have some effect on more directly observable meteorological phenomena.

3. The debris thrown into the stratosphere by the explosion may interfere with the passage of solar radiation and thereby serve to decrease the temperature of the earth.

Our present knowledge of atmospheric physics makes difficult a final authoritative evaluation of any of these possibilities.

The results of studies and experiments conducted by various organizations show the following:

1. The debris which has been thrown up into the atmosphere by past detonations was found to be ineffective as a cloud-seeding agent. Since the techniques for testing nucleating efficiency are not entirely satisfactory, the condensation and freezing nuclei produced by nuclear explosions and their effect on the formation of cloudsand the precipitation process must be continually investigated.

2. The amount of ionization produced by the radioactive material is insignificant in affecting general atmospheric conditions. Various theories on the possible connection between the electrical properties of the atmosphere and the precipitation process are still in the developmental stage.

3. Dust thrown into the air by past volcano erruptions decreased the direct solar radiation received at the ground by as much as 10-20%. The contamination of the atmosphere by past nuclear tests has not produced any measurable decrease in the amount of direct sunlight received at the earth's surface. There is a

possibility that a series of explosions designed for the maximum efficiency in throwing debris into the upper atmosphere might significantly affect the radiation received at the ground.

4. Much of the increase in severe storms reported in recent years can be traced directly to the improved methods of reporting severe storms that normally occur.

No statistically significant changes in the weather during the first ten years of the atomic age have been found, yet careful physical analysis of the effects of nuclear explosions on the atmosphere must be made if we are to obtain a definite evaluation of this problem. Although it is not possible to prove that nuclear explosions have or have not influenced the weather, it is believed that such an effect is unlikely.

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Report of the

COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION

ON

OCEANOGRAPHY AND FISHERIES

SUMMARY REPORT OF THE COMMITTEE ON EFFECTS OF ATOMIC RADIATION ON OCEANOGRAPHY AND FISHERIES

1. To Whom Is This Report Addressed?

In writing this report we have had four groups in mind -- research administrators, statesmen, scientists and the public. For those who have responsibility for the support of research, we have attempted to outline the scientific questions that need to be answered as a basis for intelligent policy, the means by which they can be attacked by classical research methods at the outset, and the broader problems of the oceans that can be hopefully attacked by the use of radioactive tracers. For the statesmen who have responsibility for national and international policy, we have attempted to formulate recommendations, based on our present small body of knowledge and our awareness of our larger area of ignorance, concerning the national and international actions and agreements that are necessary for the happy exploitation of the oceans in the new atomic age. For the scientists, we have attempted to summarize what is known about the actual and potential effects of radioactive materials in the oceanic realm and the interest of marine scientists in these substances. For the public, to which we all belong when we are outside our own specialities, we have summarized the levels of calculated risk that must be balanced against the wonderful promise of atomic energy for the welfare of mankind.

2. How Does the Atomic Energy Program Affect the Oceans?

We have considered three aspects of the atomic energy program that directly involve the oceans and, therefore, the marine sciences: weapons tests over or in the sea, disposal of radioactive wastes from nuclear power plants, and the use of radioactive substances in increasing our understanding of the oceans and of the creatures that live in the sea. These different aspects cannot easily be separated. Weapons tests and the disposal of radioactive wastes present great opportunities for studying the oceans. On the other hand, increased knowledge of the oceans is essential to avoid or minimize the destruction of marine resources in the development of atomic energy.

The continuing development of atomic energy will produce progressively greater amounts of radioisotopes, and with them greater amounts of radioactive waste material. Since the oceans cover 71% of the earth, and ultimately receive the drainage from the land, they are the principal reservoir where radioisotopes will finally accumulate. Relatively small quantities are now being added to the surface waters of the ocean as fallout from weapons testing programs, and in a few places as waste materials.

When nuclear reactors for the production of power are put into large-scale operation, as they certainly will be in the foreseeable future, the oceans will be seriously considered for the disposal of large quantities of wastes. Even if direct and intentional disposal at sea is not practiced, reactors may be built along sea coasts or on rivers near large population centers and accidental pollution may occur.

The problem of disposal of radioactive wastes is similar in character to, though potentially far greater in scope than other problems of pollution. An object lesson can be drawn from our experience with the disposal of human and industrial wastes in inland water bodies and coastal waters and with the smog problem that afflicts many of our large cities. During the early stages of the growth of industries and populations in cities, wastes were added to nearby lakes or bays, and to the air, in what seemed at the time to be innocuous quantities. As a matter of fact, the quantities were small enough to be purified by natural processes. In the course of time, however, the quantities increased insidiously so that today many natural waters cannot purify themselves and without expensive treatment are dangerous to humans.

In almost every case the problem was ignored until it had become formidable in magnitude. Short-range solutions were employed, based on inadequate knowledge, special interest, and what we now know was an unfounded confidence in the capacity of the atmosphere and the waters to absorb noxious substances. As a result, unnecessary damage was done to human beings and their environment. Much of this could have been avoided if an adequate program of scientific investigation had been started sufficiently far in advance and if scientifically based policies had been followed.

It is imperative that the nature of the wastes associated with the development of atomic energy be evaluated in advance. We know that purification of waters receiving radioisotope waste will proceed only by dilution, by precipitation and settling on the bottoms, and by the decay of radioactivity. Nothing could be done to reverse an undesirable accumulation that might result from ill-considered disposal of this type of waste.

There is no question of trying to keep all of this material out of the sea. It is certain that some of it can be safely added. Tolerability of materials must be determined, and the locations where they should be put must be wisely selected in terms of the quantity and character of the radioactivity. It is not possible today to see clearly the problems of the future; we can only define the studies that must be made to provide a scientific basis for wise evaluation, and urge that these studies be begun without delay. The costs of such studies may seem large, but they are actually negligible in terms of the potential benefits. They are also very small when compared to the total present expenditures for the development of atomic energy. We cannot wait to begin these studies until radioisotope pollution becomes serious, for it is irreversible.

3. Is There Naturally Occurring Radioactivity in the Sea?

Yes, but one of the remarkable characteristics of the ocean is the extremely low level of the natural radioactivity. Marine animals and plants living more than a few hundred feet beneath the surface are bombarded by much less natural radiation (radioactivity plus cosmic rays) than is received by terrestrial plants and animals.

For example, although radio potassium accounts for about 90% of the activity in the sea, it is present in most igneous rocks at about 100 times the concentration found in the ocean. Uranium, radium and thorium are 3000 to a million times more concentrated in rocks than in the sea. This raises an interesting scientific question concerning the character of genetic change and evolution in many marine creatures. It emphasizes the need for basic biological studies on marine organisms. Because of their experimental difficulty, such studies have been comparatively neglected during the past few decades.

4. Have Weapons Tests Added Measurable Amounts of Radioactivity to the Sea?

Yes, though in terms of the total radioactivity of the sea the amount is negligible. Radioactivity in the waters of the test area is of course very greatly increased at the time of tests, and even after diffusion over thousands of miles concentrations remain that are readily detectable. Two days after the 1954 tests in the Pacific the radioactivity of the surface waters near Bikini was observed to be a million times greater than the naturally occurring radioactivity. This material was transported and diluted by ocean currents, and four months later concentrations three times the natural radiation were found 1500 miles from the test area; thirteen months later the contaminated water mass had spread over a million square miles. Artificial activity had been reduced to about one-fifth the natural activity, but could be detected 3500 miles from the source.

5. In What Other Ways Will Radioactive Materials be Added to the Oceans?

In England radioactive wastes are being piped into the Irish Sea from an atomic installation. In the United States, wastes from laboratories and hospitals are being carried to sea in containers and dumped. At Oak Ridge, some of the fission products are discharged into the Tennessee River system. At Hanford, water from the Columbia River is used for cooling and returned to the river with some induced short-lived radioactivity. Waste products from the uranium fuel processing plants are now being confined, some in containers, others in pits in the ground. When the power reactors and fuel processing plants reach their expected development many rivers will have to be used. It will not everywhere be practical to confine the wastes locally. Transporting them to sea in barges or by other means may then be necessary in many cases. Although we may be sure the atomic installations will be carefully engineered and maintained, accidental discharge of waste may occasionally occur. On those occasions intense radioactivity may reach the sea.

6. Has the Atomic Energy Program as Yet Resulted in Serious Damage to Marine Life?

Probably no. We know that radioactive radiation is damaging to living things and that marine organisms tend to concentrate many fission product elements. But there is no evidence that any lasting damage has been done to the animal or plant populations of the sea or large inland water bodies by the release of radioactive substances.

Certainly in the weapons test area terrestrial forms were killed or injured by the tests. The evidence concerning marine life is not conclusive, but biologists feel certain that deleterious effects occurred in the near vicinity. There is, however, no evidence that populations have been affected after the dilution and transport mentioned above. This is a subject on which intensive studies are essential before a definite answer can be given. We know that "high" levels are lethal, and that "low" levels may have no direct effect, but we cannot give quantitative values for "high" and "low" except in a few cases. Low levels, which produce no measurable effect in the organism itself, may produce genetic effects and thus influence the marine populations in the future, but there is no conclusive evidence that this will be undesirable.

7. Do Living Things Take Up Radioactive Materials into Their Bodies?

Yes. Radioactive materials added to the sea can remain in solution, precipitate and settle on the bottom, or be taken up by the plants and animals that live in the water. The plants of the sea are mainly microscopic in size, but they can concentrate many thousand-fold those elements that are necessary to them. Radioactive substances are also absorbed on the body surfaces of living things. Small plants and animals serve as food for the larger forms and the radioactive materials are passed on from one to another. The amount of each element accumulated in each form depends upon the rate at which it is taken up, either directly or as food, and the rate it is excreted. Some of the radioactive materials remain in the body for relatively long periods of time and may accumulate to a considerable degree. Others may be lost rapidly and very little will accumulate.

This statement is a great over-simplification. Different plants and animals require and accumulate different elements. Shell fish, for example, concentrate calcium and strontium in their calcareous shells; fish concentrate zinc. It will be necessary to know among other things both the composition of the waste, and the populations in the area, before any particular disposal operation can be evaluated.

8. Are All the Radioactive Elements Equally Harmful?

No. Those elements that living organisms naturally accumulate and that have long radioactive half-lives are more harmful than others. Radioactive strontium, and to a lesser extent, cesium and its daughter barium, cerium, praesodymium and promethium represent particular hazards to human beings from ocean disposal.

9. How Much Radioactive Waste Will be Produced by Nuclear Power Reactors in the Future?

The answer to this depends upon how optimistic one is concerning the development of nuclear power. One estimate assumes that within about 50 years nuclear fission will be producing about half as much power annually as the peoples of the world are using today from all sources.

Accumulations year after year will eventually result in a constant quantity of radioactivity, such that the rate of radioactive decay will balance the rate of production of fission products to give what has been called the steady state. This should be approached within a few decades after full production is reached. The waste radioisotopes at this point would equal between one and two times the total natural radioactivity in the world oceans. This is roughly a thousand times the amount produced so far in weapons tests.

10. What Means Are being Considered for Disposing of Radioactive Wastes?

The methods being considered fall into two categories, isolation and dispersal. It is probable that a judicious combination of the two methods for different types of wastes or for different countries will be essential. Chemical treatment of the wastes to isolate usable fractions, or those, like strontium and caesium, that decay most slowly, offers promise in simplifying the problem. For isolation, permanent storage in tanks or introduction into geological structures such as salt domes are being studied by other committees. The only place on earth where dispersal can be considered practical is in the ocean. Because it is large and fluid, the ocean could provide immense dilution. Because of its depth, and the stratification of water-masses with differing densities, various degrees of isolation may be possible. It is a prime purpose of this report to emphasize the need for investigation as to whether this possible isolation is adequate.

11. Will It be Safe to Introduce Very Large Quantities of Radioactive Wastes from Atomic Power Indiscriminately into the Sea?

The answer is certainly no, but the strongest negative must be given for coastal waters and for the upper water layers everywhere that are the home of commercially important fishes. These surface waters interconnect and are in continuous motion. Anything added in one spot will, in the course of a few decades at most, be carried to all parts of the world. There is no place in the sea where very 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.

It should not be forgotten that the coastal waters enter the harbors and estuaries and would carry any waste materials there with them; and that many of the major fishery resources of the world are concentrated over banks and near coasts, and would become contaminated.

We must also remember that all plants and animals in the sea, from the smallest bacteria to the largest whale, play a part in concentrating, transporting, and dispersing radioactive and other dissolved and suspended materials.

12. Does This Mean that Large Quantities of Radioactive Wastes Should Never be Dumped in the Sea?

No, not necessarily, but it does mean that the length of life of the radioactive material, its role in biological processes, and the mixing rate of the ocean should be carefully studied before large quantities of wastes are introduced into the sea. Unfortunately, although we know the decay time of most radioactive substances, we know very little about the exchange processes in organisms and in the water. We do know that even the bottom waters of the deep ocean basins slowly exchange with those of the surface, but the rate of this exchange is uncertain.

13. From What Is Known, Where Would be the Safest Place to Dump Radioactive Wastes in the Sea?

At the present time it is only possible to give rough engineering estimates based on order-of-magnitude calculations.

Remembering the importance both of isolation (to allow time for radioactive decay) and dispersal (to reduce the amount of radioactivity per unit volume) the problem is to find places in the ocean where the rate of transfer of radioactive materials to the surface waters would be slow, or where great dilution would occur before radioactive materials came in contact with marine food products or human beings, and preferably where both conditions would prevail.

There are some places where a contaminant could be isolated for long periods. For example, it is estimated that in the deepest parts of the Black Sea the "flushing time" is about 2500 years. This is the time required for most of the deep water to move near to the surface and be replaced with new water mixing downward. In this respect the Black Sea is unique. Elsewhere the "age" of the deep water indicates that exchange with the near surface waters goes on less slowly. Thus in the deeps of the Atlantic and Caribbean the time required for replacement of the water with new water from near the surface is probably only a few hundred years. Some oceanographers believe that the Atlantic deep water sank from the surface in high northern latitudes about 150 years ago.

We are fairly certain that substantial amounts of long-lived radioactive materials, dumped on the bottom in the deep sea, would remain isolated for more than 100 years and that during this period they would become diluted by mixing through an enormous volume of deep water. We do not understand the nature of the physical and biological exchange processes between the deep and surface waters well enough to be able to say whether in the steady state, after decades of nuclear power production, deep sea disposal would give adequate protection of the commercial fisheries from long-lived fission products such as strontium. Large quantities of short-lived fission products could certainly be disposed of safely in this way.

14. Can Radioactive Materials be Used to Learn About the Oceans and to Increase the Harvest from the Sea?

Yes. For example, an understanding of the flow of material through food chains is essential to the effective use and conservation of the food resources of the sea. The natural elements used by the marine plants and their transfer to the commercially valuable fish and shellfish can be studied on a large scale, using radioactive isotopes. As these readily detectable substances are traced through the various steps of the food chain - plants, animal plankton, small fish, large fish - the efficiencies and inter-relationship of the various levels should become much better known. This knowledge is of fundamental importance for the evaluation of the potential of the living resources of the sea as a source of food and other marine products, and as a basis for their full utilization and conservation.

Radioactive materials, both natural and man-made, can also be used in the study of oceanic mixing processes and circulation. These processes serve to supply marine plants with the fertilizers they need from deeper waters, as well as to dilute and disperse radioactive wastes dumped in the sea. At present we cannot measure, but can only estimate the mixing rates. The ability to trace radioactive materials, even though present in great dilution, will permit us to obtain quantitative information. Improved knowledge of the mixing processes and of currents will help man to locate and evaluate unexploited resources of fish and other food organisms.

For example, thirteen months after radioactive materials were introduced into the sea by fallout from weapons tests in the Marshall Islands, a research vessel traced their distribution in the Western Pacific. The extent to which radioactivity was taken up by plankton and fish was measured, as well as the extent to which activity was mixed downward and transported westward in the western limb of the great North Pacific eddy. These measurements showed the average speed at which materials were carried away from the test area, giving convincing proof of the transport and mixing of material over a vast region.

Large amounts of radioactive tracers ranging in magnitude from curies to megacuries can be used at sea in studying oceanographic problems, including the problems of fisheries, and thus laying the ground work for increasing our harvest from the ocean. Smaller amounts are needed in the laboratory. We are here concerned not with the general problems of physiology and biochemistry but with specific ecological studies, including investigations of the efficiency of transfer of energy along the food chain, rates of filtration, concentration of elements and compounds in various tissues, the rates of accumulation and excretion of elements and compounds, the passage of substances across biological membranes, the concentration and role of biotic and antibiotic substances in the sea, the dynamics of marine populations, including the mass of living material in a given volume of water, the flux of organic substances from one organism to the other and between the organism and the sea water, and the inter-relations of animal and plant communities. In both field and laboratory experiments fission products are useful but some problems require the use of artificially radioactive substances produced by other means. An outstanding example is the use of carbon 14 to study the efficiency of various steps in the food chain. Large quantities of this material are needed for field studies in restricted water bodies. Though the cost would be high, the value of the results would more than justify the expenditure.

CONCLUSIONS AND RECOMMENDATIONS

1. Tests of atomic weapons can be carried out over or in the sea in selected localities without serious loss to fisheries if the planning and execution of the tests is based on adequate knowledge of the biological regime. The same thing is true of experimental introduction of fission products into the sea for scientific and engineering purposes.

2. Within the foreseeable future the problem of disposal of atomic wastes from nuclear fission power plants will greatly overshadow the present problems posed by the dispersal of radioactive materials from weapon tests. It may be convenient and perhaps necessary to dispose of some of these industrial wastes in the oceans. Sufficient knowledge is not now available to predict the effects of such disposal on man's use of other resources of the sea.

3. We are confident that the necessary knowledge can be obtained through an adequate and long-range program of research on the physics, chemistry, and geology of the sea and on the biology of marine organisms. Such a program would involve both field and laboratory experiments

with radioactive material as well as the use of other techniques for oceanographic research. Although some research is already underway, the level of effort is too low. Far more important, much of the present research is too short-range in character, directed towards ad hoc solutions of immediate engineering problems, and as a result produces limited knowledge rather than the broad understanding upon which lasting solutions can be based.

4. We recommend that in future weapons tests there should be a serious effort to obtain the maximum of purely scientific information about the ocean, the atmosphere, and marine organisms. This requires, in our opinion, the following steps: (1) In the planning stage committees of disinterested scientists should be consulted and their recommendations followed, (2) funds should be made available for scientific studies unrelated to the character of the weapons themselves, and (3) the recommended scientific program should be supported and carried out independently of the military program rather than on a "not to interfere" basis.

5. Ignorance and emotionalism characterize much of the discussion of the effects of large amounts of radioactivity on the oceans and the fisheries. Our present knowledge should be sufficient to dispel much of the over-confidence on the one hand and the fear on the other that have characterized discussion both within the Government and among the general public. In our opinion, benefits would result from a considerable relaxation of secrecy in a serious attempt to spread knowledge and understanding throughout the population.

6. Sea disposal of radioactive waste materials, if carried out in a limited, experimental, controlled fashion, can provide some of the information required to evaluate the possibilities of, and limitations on, this method of disposal. Very careful regulation and evaluation of such operations will, however, be required. We, therefore, recommend that a national agency, with adequate authority, financial support, and technical staff, regulate and maintain records of such disposal, and that continuing scientific and engineering studies be made of the resulting effects in the sea.

7. We recommend that a National Academy of Sciences-National Research Council committee on atomic radiation in relation to oceanography and fisheries be established on a continuing basis to collect and evaluate information and to plan and coordinate scientific research.

8. Studies of the ocean and the atmosphere are more costly

in time than in money and time is already late to begin certain important studies. The problems involved cannot be attacked quickly or even in many cases, directly. The pollution problems of the past and present, though serious, are not irremediable. The atomic waste problem, if allowed to get out of hand, might result in a profound, irrecoverable loss. We, therefore, plead with all urgency for immediate intensification and redirection of scientific effort on a world-wide basis towards building the structure of understanding that will be necessary in the future. This structure cannot be completed in a few years; decades of effort will be necessary and mankind will be fortunate if the required knowledge is available at the time when the practical engineering problems have to be faced.

9. The world-girdling oceans cannot be separated into isolated parts. What happens at any one point in the sea ultimately affects the waters everywhere. Moreover, the oceans are international. No man and no nation can claim the exclusive ownership of the resources of the sea. The problem of the disposal of radioactive wastes, with its potential hazard to human use of marine resources, is thus an international one. In certain countries with small land areas and large populations, marine disposal of fission products may be essential to the economic development of atomic energy. We, therefore, recommend: (1) that cognizant international agencies formulate as soon as possible conventions for the safe disposal of atomic wastes at sea, based on existing scientific knowledge; and (2) that the nations be urged to collaborate in studies of the oceans and their contained organisms, with the objective of developing comparatively safe means of oceanic disposal of the very large quantities of radioactive wastes that may be expected in the future.

10. Because of the increasing radioactive contamination of the sea and the atmosphere, many of the necessary experiments will not be possible after another ten or twenty years. The recommended international scientific effort should be developed on an urgent basis.

11. The broader problems concerned with full utilization of the food and other resources of the sea for the benefit of mankind also require intensive international collaboration in the scientific use of radioactive material.

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Report of the

COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION ON AGRICULTURE AND FOOD SUPPLIES

REPORT OF THE COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION ON AGRICULTURE AND FOOD SUPPLIES

I. General

The Committee interpreted its task as requiring its members to survey the scientific aspects of that great sequence of events which precedes the delivery of food items to the ultimate consumer, and to do so from two separate viewpoints. These were (1) the beneficial effects that may result from the deliberate involvement of radiation of any sort with constructive intention, or what has been spoken of so frequently as the "peaceful uses of atomic energy," and (2) the harmful or disadvantageous effects of radiation of any sort due to nuclear warfare, to accidents involving atomic power plants, or even to a slowly rising background of radiation that conceivably may follow as a result of atomic technological developments in industry.

Public and private funds are currently being expended in the United States for research in agriculture and food processing at a rate in the vicinity of 300 million dollars annually. An undeterminable but not insignificant fraction of this considerable body of research involves radiation or radioisotopes. Members of the Committee did not believe it to be incumbent upon them to defend or justify, to criticize or to challenge applications of atomic radiation to agriculture that have been developed or are under discussion. They did not wish to evaluate the programs of particular agencies or groups, but instead with judicial mind to examine the accomplishments and the potentialities, the implications and the limitations of radiation as related to the production and processing of agricultural products.

One broad conclusion is that there is not imminent any drastic change in agricultural production as a result of the application of radiation. However, radiation techniques provide new tools for research and may aid agricultural production by improving and enhancing the efficiency of production methods.

The Committee is strongly of the view that the applications of radiation will be of far greater immediate consequence to agricultural research than directly to agriculture, and that most of the benefits that may arise to agriculture, as manifest in the availability of an adequate and varied supply of wholesome food for man, wherever he may be, will come as a summation of many improvements, small and large, in materials, in plants and animals and in the technology of husbandry and processing developed through programs in agriculture and food processing research.

Changes therefore may be expected to come in a series of little steps, none of which in themselves may be of great impact, but which, through the years, are likely to be impressive in their total.

Another broad conclusion is 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. Levels of radiation considered tolerable by man are below those believed to have effects in plants or animals that would place food production in jeopardy. However, the high levels of radiation which might develop in small or large areas as a result of atomic or thermonuclear weapons in wartime, or from mishaps with nuclear power plants in peacetime could have catastrophic effects on agricultural production that might be of long duration, because of injury to personnel and animals, disruption of services, and contamination of soil, vegetation and water supplies.

II. Tracer Studies in Agricultural Research.

In the consideration of the beneficial effects of radiation the Committee endeavored, not wholly successfully, to separate in its thinking those benefits that may arise from additions to the pool of basic knowledge about plants and animals and their welfare, from those more direct effects that may specifically result from the exposure of plants, animals or agricultural products to radiation. Tracer studies in the biological sciences have already been enormously fruitful in aiding the elucidation of essential metabolic processes in plants and animals, and may be expected to be increasingly so as the number and diversity of such experiments increases. When there is knowledge and understanding of a process then comes the opportunity to control it for a desired end; in this way the art of agriculture is transformed to the science of agriculture.

They endeavored to make the separation mentioned above because of the conviction that there is nothing unique about radioisotopic studies as applied to agricultural research. Tracer techniques, however, frequently permit answers to be obtained to questions which seemed previously unanswerable by conventional experimentation. The involvement of isotopes puts a new dimension into metabolic studies, and areas, formerly dark, may now stand out in relief.

It is worthy of comment that many of the applied problems involved in the arts or technology of agriculture are as susceptible to study by procedures involving radioisotopes as are those more basic questions of plant and animal physiology or nutrition. Excellent examples of this type of employment of isotopes are to be found in work on the placement and recovery of phosphorus fertilizers in soils, the efficiency of various methods of application of insecticides, fungicides and herbicides, the determination of post-harvest residues of such chemicals, the extent of utilization of feed components by animals, etc. It is to be anticipated that there will be greatly increased use of tracer radioisotopes in the solution of such applied problems, and that the immediate dividends from such research may be considerable. Further, it is likely that new methods of employing isotopes advantageously will be developed; the ingenuity of investigators in this field should not be underestimated.

Because of the unanimity of their views as to the enormous potentialities of isotope tracers as a research tool in agricultural science and biology generally, the Committee gave some consideration as to whether there are limitations in facilities for training or funds for specialized equipment for such studies. The consensus seemed to be that motivation for the use of such techniques must come from individual investigators themselves, that the necessary know-how is to be found in almost all research institutions, and that progress in agricultural research is not at the moment limited by inadequacies in dissemination of knowledge and techniques. There was, however, a feeling that much of the graduate training in this field is rather informal, that more universities might consider establishing courses in which the methodology, techniques and principles of this new and powerful science are expounded, and that there is an additional need for an advanced training program for specialists in radiochemistry and radiobiology who may be developers of new techniques or interpreters of new applications of potential value in agricultural research.

III. Effects of Radiation on Crop Production.

It is abundantly established that mutations can be induced in many plant species by exposure to x-radiation, gamma radiation and other forms of radiation. The changes which result are possibly due to chromosome deletions or abberations. There is some difference of opinion as to whether radiation-induced mutants intentionally obtained are qualitatively identical with those which occur spontaneously from naturally occurring mutagenic agents, but there is no doubt that their frequency is increased. Even so the mutation rate in most species is still very small, and furthermore most mutations are disadvantageous.

The investigator seeking to exploit this phenomenon must expect to have to handle very large populations, and so far has been able to look only for desirable changes that are reflected in morphology or appearance and therefore can readily be seen, 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 one or more exhibiting resistance to infection.

It is likely that characters at present unrecognized also undergo change and that there are unexplored potentialities for effecting improvement in quality that may alter the demand for the plant, or in physiological properties that may alter the relationships of the plant with its environment.

It would be a mistake to imply that this new development has greatly simplified the tasks of those involved in crop improvement. On the contrary, it has made them more complex, but, by extending the boundaries, offers many new possibilities. It is not to be expected that acceptable new agronomic varieties can be obtained by simple irradiation of present varieties, though 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.

As yet relatively few new varieties of economic plants, developed from radiation-induced mutants, have actually been introduced and widely planted. These, however, do attest to the potentialities of this procedure. Much of the research effort in this field has properly been devoted to the investigation of techniques, to such vital questions as the determination of the particular stage of development at which radiation exposure may be most effective, and the comparative mutability of crop species. It appears that different species cannot be expected to respond in an identical manner. More perhaps is known about this aspect of corn genetics than of any other major crop plant.

Mutations in micro-organisms may similarly be induced by exposure to various types of radiation, though at considerably higher radiation levels than with crop plants. The changes induced have been shown to include the degree of virulence and host range of certain pathogenic fungi. The suggestion has repeatedly been made that the plant pathologist should examine this phenomenon so as to anticipate disease-resistance requirements in a breeding program. As yet, however, there have been no significant results along these lines. Considerable success has been achieved in the development of greatly enhanced antibiotic production by some molds through radiation-induced mutation and selection. Similar genetic changes in the case of other micro-organisms have produced information about the likelihood of genetic control of metabolic processes.

There is considerable evidence that bud mutations or somatic mutations can be induced by radiation, and that this phenomenon can be exploited in the development of new strains of crop plants that are normally propagated by cuttings and grafting. This may be of special value in the improvement of some such crops, but as yet there have been no striking accomplishments in this direction. Progress in such studies is however inevitably slow because of the nature of the materials, the length of time necessary to recognize a desirable change, and to produce the stocks necessary for field evaluation.

Since the mutation rate of plants may be enhanced by radiation, presumably there is some possibility of the appearance of undesirable mutants in areas where the background radiation becomes higher than normal for any reason. This may be of some significance in connection with waste disposal practices or atomic accidents. There is, however, no evidence of such changes in areas containing radioactive springs or ores. This may be due to lack of intensive examination of the vegetation of such areas, and such surveys are to be encouraged. However, the likelihood of appearance of undesirable lines under radiation levels that would be tolerated on other grounds seems small.

There is no evidence that plant growth is stimulated or crop yields increased by exposure to low levels of radiation, despite earlier well-publicized claims to this effect. Radioactive fertilizers, used in a conventional manner, produce yield increments no greater than expected from ordinary fertilizers.

Plants accumulate nutrient elements present in the root zone in solution or absorbed onto soil colloids, but non-nutrient elements are not excluded and may similarly be taken up. The availability of radioisotopes has greatly improved the understanding of plant nutrition and soil-plant relationships, and may be expected to aid substantially in the improvement of cultural practices, as indicated earlier. Through the use of isotopes it has been demonstrated unequivocably that certain elements can enter the plant through the leaves. This is of some consequence in relation to fall-out. Radioisotopes of long life or high activity if deposited in fall-out from an atomic or thermonuclear incident are likely to be accumulated in crop plants by root uptake from the soil and entry through the foliage. Some of the products deposited may be initially quite insoluble, but may become soluble through weathering. Others, initially soluble, may be irreversibly fixed by many soils in a form not readily available to crops. It appears at present that Sr^{90} and I^{131} are the chief radioactive elements which are of concern in such circumstances. The subsequent use of such crops presents a great diversity of problems depending on the level of radioactivity, its nature and the specific use of the crop. The Committee was interested to learn that the Department of Agriculture is preparing for farmers some informational material relating to these problems.

The Committee desires to examine further the available information on the inter-actions of fall-out components with soil, their entry and accumulation in crop plants in order to determine whether there is available the necessary basic information from which appropriate agronomic recommendations could be formulated for agricultural operations in areas that may have undergone any likely level of contamination.

IV. Effects of Radiation on Animal Production.

Whereas it appears that crop improvement programs may be considerably aided by the availability of radiation-induced mutants that may have certain desirable characteristics capable of incorporation into an agronomically acceptable variety, currently available evidence does not suggest that a similar approach with animals would be so rewarding. This statement is made not from a belief that farm animals are inherently less responsive to radiation than plants but because physical differences of size, cost, generation time, etc., militate against extensive studies with animals, and act as obstacles that cannot readily be overcome. Probably only with poultry and to a lesser degree with swine would it be possible to handle large enough populations, and even here, if one extrapolates from the smaller laboratory animals, the chances of improvement seem slim. At present one such study, with chickens, is known to be underway.

Limited whole-body exposure studies with farm animals have primarily been carried out to investigate physiological and pathological changes, often with the intention of transferring the information by analogy to problems of responses in man. The sequence of changes induced in most farm animals by heavy radiation exposures has been well defined. There are one or two examples however of the use of radiation exposure as a research tool for inhibiting certain functions in animals. For example various functions in the oviduct of poultry can be blocked by proper radiation techniques thereby permitting a study of the contribution made by the parts of this organ.

Much of the work with radioisotopes in the animal field centers around problems of animal nutrition and metabolism, and substantial progress has been made both in the elucidation of fundamental problems of animal physiology as well as in those of a more applied character, such as the utilization of feed constituents, and the incorporation in animal tissues of inorganic constituents of forages. The experimenters in this field at present encounter one serious difficulty, which in the case of the larger farm animals greatly limits the scale of activity. This is the problem of the salvage or disposal of animals after use in experiments involving radioisotopes or radiation exposure. Even in the case of short half-life isotopes and at tracer levels only, the animals cannot be marketed through the usual outlets. This problem is of course much more serious with dairy or beef cattle than with hogs or poultry because the cost to the program is so much greater. Moreover, this limitation tends to restrict undesirably the scale and scope of such experiments, with the result that the conclusions may be less surely established than if the numbers of animals used were larger.

It appeared to the Committee, therefore, that essential research on farm animals using radioisotopes or radiation is being discouraged by the high costs involved because animals must be destroyed at the termination of experiments. It recommends that a special committee be appointed to study this problem and to develop procedures and standards that, if followed and enforced, would adequately protect the consumer, but permit the marketing of animals that in experimentation have been brought into contact with radioactive substances or exposed to radiation.

The welfare of the livestock population is enhanced if troublesome insect pests can be controlled or eradicated. As mentioned earlier, insecticide studies have been greatly aided by the availability of radioisotopes as tracers, but in addition there may be certain opportunities for control of insect pests by taking advantage of radiation-vulnerable stages in their life cycles. Eradication of the screw worm fly from the southeastern United States is to be attempted, based on the virtual elimination of this fly from the island of Curacao by the release of males rendered sterile by radiation exposure. This technique may not be generally applicable to all insect pests.

V. Radioisotopes in Agricultural Products and Foods.

The Committee discussed in detail some of the difficult problems that may arise because of the presence of a radioisotope burden in agricultural products and foods higher than that "naturally occurring". The applicable legislation in this area is clouded with uncertainties, because the very possibility was not envisaged by those who enacted the laws and defined the responsibilities of the agencies that protect the public food supply. There are no permissable limits for radioisotopes in foods; any burden above the "natural" is regarded as undesirable. The current interpretation of the law places isotopes in the same category as poisonous additives. It is difficult, however, to be wholly consistent in this, inasmuch as the normal radioisotope burden varies considerably in different agricultural products, and in the same product from different locations. Moreover, the testing of atomic and nuclear weapons is placing in soil, water, and air, the world over, radioisotopes not formerly present, though at extremely low levels. The "natural content" of foods now consumed by animals and man is not the same as in the pre-atomic age. Though extremely small, the increment is measurable, and inescapable.

It is to be anticipated that there will be in the years ahead a slowly rising background of radiation manifest in agricultural and food products by the presence of the isotopes of elements not previously found therein or of "unnatural" levels of radioactivity. Atomic warfare might greatly increase the rate of this development. As pointed out earlier in this report, radiostrontium is particularly the element which would cause concern in the latter event. Forage directly contaminated with fall-out, if consumed by farm animals soon after deposition might cause radiation injury from the presence of insoluble radioactive products. Strontium is metabolically similar to calcium and moves into bone and other calcium-accumulating tissues or fluids. Much is known of the relative behaviors of calcium and strontium but there appears to be no way of wholly preventing strontium retention. There is some evidence that poultry may "decontaminate" or "detoxify" themselves by reason of a continued dilution through transfer to egg-shell. In meat animals certain tissues might be consumable if boned out, but such an expedient would be beyond the ordinary scope of meat inspection. Dairy products would contain radiostrontium for some considerable time after ingestion of strontium-containing forage. Moreover, all available feeds, in heavily contaminated areas, might contain significant levels of radiostrontium, perhaps for years.

At present it is not possible to say at what level a food, otherwise wholesome, becomes unwholesome or deleterious by reason of the presence of an unnatural burden of radioactivity. There is a great deficiency of requisite data on the long-term biological effects that may follow the ingestion of such foods by animals and man. Situations in which such information might be of great public importance are not inconceivable and possibly inevitable.

The Committee therefore urgently recommends that appropriate experimentation be immediately activated to provide specific information about possible total or cumulative biological effects that might follow the ingestion of such foods. It further urges that the planning of such experiments be broadly based, and that the development of the experimental designs and details of their subsequent execution be most carefully considered in order that the emerging data will be acceptable as a basis for the crucial decisions that ultimately will have to be taken, and directly of value to the regulatory agencies charged with the protection of the public interest.

VI. Environmental Changes and Ecological Studies.

In the decades ahead there is a strong possibility that the general background of radioactivity in agricultural areas will rise. Contributing to this would be fall-out, if weapons-testing continues, and wastes from nuclear power plants or isotope processing plants. As indicated in the report of another Committee every effort will have to be made to contain radioactive wastes. Atomic warfare, or accidents involving nuclear power sources could of course greatly augment the background and pose difficult problems of land-use for agricultural purposes. Limited ecological studies are in progress in the vicinity of certain A. E. C. installations, but it may be wise to consider this general problem somewhat more widely and to attempt to establish, through careful sampling, the present background in representative agricultural areas, and in their chief crop and livestock products.

Research activities might appropriately be carried out on areas near weapons test sites where substantially greater changes in background would be anticipated. The distribution in the environment, in the soil at various depths, in the vegetation, in the wildlife, in the streams, etc. would all be pertinent. The rate of accumulation in soil as affected by land use ought to be studied. Forested land, range land, rotation grassland, and plowland, irrigated and non-irrigated, may each present a different situation. It is possible that certain of the State Agricultural Experiment Stations might be in a position to undertake limited surveys of this type on areas likely to be under their control for some considerable time in the future.

The Committee recognized clearly that sustained monitoring and ecological research activities of this type are expensive and are not apt to be professionally rewarding to the individuals participating therein, because trends and conclusions would emerge only slowly. However, to be able to recognize changes in the levels of radioactivity in the environment and in products removed therefrom, and to follow movements in the system, may well be in the public interest from a long-range viewpoint.

VII. Effects of Radiation on Plant or Animal Products (Food Processing).

A recent development in food technology, potentially of considerable and possibly dramatic significance, is the recognition of the fact that radiation can be used as a means of preserving certain foodstuffs or of lengthening shelf life, either unrefrigerated or refrigerated. The radiation source may be gamma rays or high energy electron beams. No radioactivity is induced in the irradiated material. Feeding experiments to date indicate that foods so irradiated will prove to be suitable and safe for consumption by man. Parasites in meat and meat products can be killed by exposure to penetrating radiation; and undesirable post-harvest changes in plant products, such as the sprouting of potatoes, can be delayed.

The prime objective in radiation processing is to destroy microorganisms, or so greatly to reduce the microbial population (radiation pasteurization) that spoilage is long delayed. To accomplish this, very heavy radiation exposures are necessary because microorganisms are much less sensitive to radiation than are animals and higher plants. The food processor is particularly attracted by the fact that the radiation exposure can and should be carried out after packaging.

The acceptability of some radiation sterilized foods is open to doubt because of the development of off-flavors, and changes in odor or in the texture of the tissues. Much of the developmental work in this field however has been of a rather empirical nature, and it is possible that through research means may be found to repress some of these undesirable changes.

Although the feasibility of radiation sterilization has been amply demonstrated, the economics of the various processes have not yet been established. This development has largely been financed by the military with the Army Quartermaster Corps as the primary agency involved, but there has been a broad basis of cooperation in industry and elsewhere, with some technical guidance and evaluation by Advisory Committees of the National Academy of Sciences. Having in mind the magnitude and coherence of the current broad programs in this area the Committee was of the opinion that the potentialities of this use of radiation are being thoroughly explored, and that the interests of the food consumer will be adequately protected. At a later date the Committee expects to review particularly the evidence of wholesomeness and acceptability of irradiated foods.

VIII. Committee Membership.

The names and institutional affiliations of members subscribing to this report are listed below. In their deliberations they were aided by Douglas M. Whittaker of the Rockefeller Institute and Charles I. Campbell of the staff of the National Academy of Sciences-National Research Council. As Consultants the Committee is indebted to A. J. Lehmann, Food and Drug Administration, Robert Somers, Meat Inspection Service, U. S. D. A., J. Wolff, Atomic Energy Commission.

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Report of the

COMMITTEE ON DISPOSAL AND DISPERSAL OF ATOMIC WASTES

SUMMARY REPORT OF THE

COMMITTEE ON DISPOSAL AND DISPERSAL OF RADIOACTIVE WASTES

Introduction

Experience in handling the waste disposal problems to date is mostly limited to conditions as they exist in the areas of the national atomic energy establishments. The determination of hazards from the disposal of wastes in these areas, most of which are in remote and somewhat isolated regions, involving relatively short periods of time, has to date revealed no deleterious effect on the public or its environment.

This does not provide, however, a completely adequate basis for projecting the magnitude of the hazard into the vastly expanded realm of industrial atomic power production. Not only does the problem itself take on new significance with the projected amount of wastes, but environmental factors which may lie dormant under conditions existing in the remote areas take on full blown importance when viewed under the more stringent requirements for highly populated areas.

Many such problems immediately come to the surface as a result of consideration of the long-term legal and insurance aspects. These problems reflect first of all a need for deeper understanding of the basic issues and for more refined measurements, and not merely for greater but still unknown factors of safety. Long-term responsibilities, moral, legal, and financial, stemming from the ownership of atomic wastes simply come into sharp focus when it is emphasized that the radioactive life of the wastes would probably exceed by several centuries the official life of the organization itself. Legal and insurance requirements, therefore, will undoubtedly have a great deal to do with the shaping of rigid administrative policies with respect to these long range aspects of the atomic waste disposal problem. It may be difficult to maintain an adequate balance between objectives which primarily must emphasize the legal requirements and those which in the broad biological sense must establish the foundations for a truly preventive approach to this problem.

Present Status of Problem

The following listing summarizes the conclusions regarding the status of waste dispersal and disposal operations:

1. The safe handling and ultimate disposal of radioactive wastes is an important technical, economic and administrative aspect of the nuclear energy industry. Waste operations must be thoroughly integrated with all other phases of nuclear energy operation.

2. From a technological standpoint the highly radioactive wastes resulting from the processing of reactor fuels constitute the bulk of the problem. To date essentially none of those wastes has been disposed of, i.e., returned to the environment. Tank storage is presently utilized as an interim answer to this problem.

3. Wastes resulting from normal reactor operations are an important consideration, but technically represent a problem for which solutions are generally available.

4. Research and development have indicated possible feasible systems for ultimate controlled disposal of highly radioactive wastes, but considerably more work is required to bring these systems to the point of economic operating reality.

5. Major technical and economic considerations underlying the waste problem are:

   a. Characteristics of nuclear fuels and chemical (or other) processing associated with them.

   b. Separation of specific isotopes from the wastes and use of these materials to economic advantages.

   c. The proper selection of the site for nuclear facilities - especially reactor andfuel processing plants.

   d. The detailed quantitative evaluation of the environment in order to assess its capacity to receive radioactive materials without creating deleterious effects on the environment.

   e. Systems for the physical handling and transportation of highly radioactive materials.

6. Major policy and administrative considerations relevant to the regulation of the waste problem are:

a. The establishment, perhaps through private enterprise, of suitable waste disposal services.

b. The regulation and control of waste disposal practices through existing and traditional state, interstate and local channels where feasible.

c. Continuation and strengthening of established practices in relations with the public and its agencies.

Relation to Nuclear Industry Growth

Based on the best estimates available (which vary over rather wide ranges) and, to a substantial extent on technical judgment, the indications are that the principal source of fission products from nuclear reactors in the next decade will arise from the generation of electricity at nuclear powered central stations. On the basis of present developments, the second most important source probably will be reactors for naval service. Compared with these, other sources are comparatively small and amount to substantially less than the uncertainty in the estimates of the principal uses.

By 1965 the average rate of reactor heat release is estimated to be about 11,000,000 kilowatts. Naval service will account probably for 20 per cent of this output in 1965. This rate of heat release will result in the production of somewhat over 10 kilograms of fission products per day in 1965.

In addition, the presence of radioactive wastes in quantity will have a profound effect on certain non-nuclear industries which may be damaged by air or water contaminated with radioactive wastes. Numerous wet-processing industries are likely to be detrimentally affected by radioactive wastes even in trace concentrations. Among this vulnerable group are those requiring water of the highest purity, such as for the manufacture of photographic film. Other industries which should be alerted to the problem are pharmaceutical manufacturers and food processing companies. It is not possible, at this time, to enumerate with assurance the industrial processes which can be completely eliminated as subjects of this potential hazard, without the assembly of extensive research and statistical data applicable to specific operations.

Relation to Fuel Processing and Types of Reactors

Neither the type of fuel nor the length of irradiation time greatly influence the accumulated total radioactivity of fission products. After approximately three years decay the residual radioactivity is essentially the same for various irradiation times, assuming constant heat generation during the irradiation period.

Essentially all of the radioactive material from fuel separations processes must be kept from the environs to maintain human exposures within maximum permissible limits. An important problem which possibly limits storage volume is the rate of heat removal from the containers. After solvent extraction wastes are concentrated by supplied heat to about 2000 gallons per ton of irradiated uranium, the heat of radioactive decay will continue the concentration to 100-500 gallons per ton. Practical heat removal mechanisms may require that more concentrated waste produced by other separations processes be diluted to the same volume range. More concentrated fluid wastes also need stronger, less economical containers. The volumes of stored waste accumulated by 1980 are estimated at 20×10^7 gallons, by 1990 at 60×10^7 gallons and by 2000 at 240×10^7 gallons.

The future possibility of high burn-up of reactor fuels might ultimately result in a situation where processing may be unwarranted. This would not change accumulation of fission products, but would have a profound effect on waste storage and disposal considerations. Similarly, the development of non-aqueous chemical processing methods would be important in modifying the waste management problem.

Isotopes Problems

The technical and administrative problems associated with the transport, use and disposal of radioactive materials in medicine, biology, and industry will undoubtedly grow in complexity and quantity as the demand for the use of these radioactive materials increases. The expanding demand is already apparent in the rapidly increasing number of individual isotope users as evidenced by the expansion of the isotope distribution program. The program for the distribution of reactor-produced radioisotopes is nearing one decade, having been initiated on August 2, 1946. During this period more than 100,000 shipments of radioisotopes have been made from AEC facilities to some 3,200 institutions throughout the United States. These materials are being applied in science, agriculture, medicine and industry. The Oak Ridge National Laboratory, the principal radioisotope production facility in the United States, has shipped approximately 130,000 curies to date.

All indices of radioisotope utilization reveal continued rapid growth. A look at the last three years of the program shows a growth in the number of using institutions from 1,400 to 3,200. This is an increase of approximately 125%. There has been a 100% increase in annual numbers of shipments made since January 1 1953. The principal growth during the period has been in the industrial use of radioisotopes.

However, of even greater significance in connection with environmental and hazard control problems is the ever increasing desire for larger and larger individual sources of radioactivity. Requirements for intense radiation sources are obviously at their earliest stages. Such uses as food and pharmaceutical sterilization, promotion of chemical reaction, and other yet unknown applications will undoubtedly result in a much more extensive use of mobile and more widespread sources of intense radiation.

Increased use, especially of highly active materials and the increase in the production of by-product materials at widely scattered geographical locations will result in ever increasing new technical and especially administrative problems in both the transport of the material and the disposal of the wastes, in order to protect the environment against normal and potential emergency hazards.

Compliance with existing transportation regulations present few significant problems in the shipment of by-product material even though certain specific limitations exist. However, consideration should be given to a complete critical review of existing ICC, Civil Air, Coast Guard and Postal regulations to bring them in line with current requirements and radiation safety knowledge.

The radiological health and safety record in the nation-wide use of radioisotopes is excellent. Incidents which have come to the Atomic Energy Commission attention involving significant overexposure of personnel are exceedingly small; fewer than 10. In large measure this may be attributed to active educational efforts in radiological protection through a field advisory service to isotope users and through effective and practical licensing practices.

At present activity levels of use of radioisotopes and with the wide dispersal of users substantial environment health problems do not exist due to waste disposal or other practices resulting in the introduction of radioisotopes into the environment.

Items Requiring Further Study

The following listing summarizes conclusions in this area:

1. Geophysical and geochemical aspects of ultimate disposal of highly radioactive wastes.

2. Site selection for various nuclear facilities, particularly chemical processing plants and their location with respect to suitable waste disposal areas.

3. Transportation of highly radioactive materials.

4. Relationship of introduction and development of nuclear facilities to basic public health, social and economic situations extant or resulting from such development.

Problems of Accidental Hazards

The following conclusions in respect to the consequences of accidents involving radioactive materials appear warranted:

1. The problems of waste disposal could be international in character and must be solved technically so that the total environment is maintained at a low level of radioactivity in order that accidents that are bound to occur will not be disastrous.

2. The type of accident that could result in a catastrophic spread of radioactive materials is the complete vaporization of the core of a reactor and its release to the surroundings. The probability of a catastrophic accident with a properly designed nuclear reactor is extremely small.

3. Reactor waste processing plants or storage facilities offer a greater hazard on a long-term basis than any single reactor.

4. Accidents in handling, transport, and chemical separation of radioactive materials, while locally severe, should not affect a wide public area and, in all cases, the contaminated areas can be cleaned up.

5. The probability of accidents in handling radioactive isotopes and low-level radioactive materials is similar to that in handling other types of lethal substances.

6. Use of nuclear reactors to drive ships appears feasible from a consideration of the consequences of possible accidents provided uranium-233 and plutonium are kept to a minimum. The technology of the use of nuclear reactors to drive locomotives and commercial airplanes has not developed to the point where the committee can form a judgment as to the consequences of possible accidents.

7. Development of improved methods to limit the volumes of wastes produced in nuclear power reactors is justified from the viewpoint of the hazards due to possible accidents.

8. Continuous and vigorous appraisal of reactor and fuel processing plants design and operation and waste storage will be required in all nations using atomic energy in order to keep the radioactivity level of the world environment at tolerable levels.

9. Improved safety devices for control of transients in nuclear reactors should continue to be vigorously developed.

10. Further tests are required of reactors to evaluate their ability safely to withstand power excursions which may occur as a result of unusual operating circumstances.

11. Until such time as advances in the technology of reactors lessen potential hazards substantially, sealed buildings properly designed, constructed, and tested should be required for all nuclear reactors to be built in or near populated areas.

12. All operations involving radioactive materials in sufficient amounts to create possible health hazards should be supervised by trained and responsible people.

Fall-Out Considerations

It is apparent that as of the present time the dispersal of radioactive material resulting from weapons testing has not been an environmental contaminant of substantial public health significance. However, because of various unknown factors regarding distribution and ultimate fate of this material, plus the potentials of possible wider spread and more frequent weapons testing it is also apparent that the subject in all of its aspects merits meticulous and continuing attention. The problem of fall-out is one of international significance and should be studied and evaluated on that basis, perhaps looking forward to international cooperation in control.

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