A REPORT TO THE PUBLIC

ON THE

Biological Effects of Atomic Radiation

Based on the

1960 Summary Reports

of the

NATIONAL ACADEMY OF SCIENCES

COMMITTEE ON THE BIOLOGICAL EFFECTS OF ATOMIC RADIATION

NATIONAL ACADEMY OF SCIENCES — NATIONAL RESEARCH COUNCIL

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I. INTRODUCTION

In 1956, the National Academy of Sciences published the first of a series of reports on the Biological Effects of Atomic Radiation[1]. These reports were designed to provide technical information about the effects of high-energy radiations on living things, with man, of course, the object of prime importance. The 1956 reports were well received and appeared to fill a genuine need.

Since then, the rapidly developing uses of atomic radiation for peaceful purposes have continued to play an increasing role in the lives of all mankind. Outstanding examples are the expanding use of radioactive isotopes in medical diagnosis, therapy, and research, and the installation of nuclear reactors for power and propulsion. Because of these developments, the six Committees responsible for the first reports have continued their studies and have now prepared a 1960 supplement to the original reports[2].

An increased public interest in the potential hazards of radiation has developed. Along with this increased interest, there has come a desire for immediate answers to many complex questions. As in every other area of science, there are today many questions about radiation hazards which are unanswerable with present data.

Data needed to provide a sounder basis for recommended practices can only come from future research. In some areas, an intensified research effort will produce earlier results. In other areas, time is an insurmountable barrier to accelerated progress.

The steady accumulation of scientific information since 1956 has not brought to light any facts that call for a drastic revision of earlier recommendations. In the presently submitted documents, more attention has been paid to future objectives and to the research programs needed to attain them.

The summary reports from which this material has been prepared will be followed by a series of more detailed considerations of specific fields. As before, all Committee activities have been supported by funds provided by the Rockefeller Foundation.

[1] NAS Summary Report, 1956.
[2] NAS Summary Report, 1960.

II. ABSTRACTS OF THE COMMITTEE REPORTS

Genetic Effects

The trends in the exploitation of nuclear energy make it clear that man-made ionizing radiation is a permanent addition to the hazards of human existence and well-being. World populations can now be exposed, usually involuntarily, to agents detectable only by sensitive instruments. These agents are known to produce deleterious changes in hereditary material.

Geneticists have a grave responsibility to make the best possible estimates of the genetic injuries anticipated from small radiation exposures. In addition, they must furnish guidance and impetus to research programs so that improved future estimates can be made as soon as possible.

Since the 1956 report of this Committee, there have been a number of significant developments in genetics and radiobiology. New insight has been gained into the nature of the genetic material, the characteristics of the mutation process, the manner in which genes control the processes of development, and the ways all of these are affected by various kinds of radiation. Yet, in some respects, the estimation of human radiation hazards is more difficult than it appeared to be in 1956. For one thing, the assumed constancy of the total genetic effect irrespective of dose rate, for which there seemed to be good evidence at that time, has turned out not to apply to spermatogonia and oocytes, which, as far as human hazards are concerned, are the most important stages of the male and female reproductive cells.

Among the reported new findings that have a bearing on the assessment of the genetic effects of radiation and that have been considered by the Committee are the following:

1. In mice, fewer mutations are produced in spermatogonia and oocytes by chronic irradiation (i.e., a low dose rate) than by the same amount of acute irradiation (i.e., a high dose rate) when the total dose is the same. However, the data are not yet sufficient to establish the precise quantitative relations between dose and effect at low doses for either acute or for chronic irradiation. A similar dose-rate effect has been reported for mutations induced in oogonia (immature female reproductive cells) of Drosophila.

2. At the time of the previous report, there was little information on the results of irradiation of female mice. Data now available indicate that late oocytes are not widely different from spermatogonia in their sensitivity to induction of mutations by acute irradiation. If anything, they suggest greater sensitivity.

3. There is some shortening of life in the progeny of irradiated male mice, as well as in the irradiated mice themselves.

4. Studies of human cells grown in tissue culture have shown that doses as low as 25 r will cause detectable chromosome breakage in a significant proportion of the cells.

5. Additional studies on children of survivors of the atomic bombings at Hiroshima and Nagasaki, and on children elsewhere whose parents received radiation for medical or other reasons, suggest that the sex-ratio in these children has been slightly but significantly altered as a result of radiation-induced mutations affecting prenatal viability. The fact that the sex-ratio may be influenced by many factors indicates the need for conservatism in interpreting this finding.

In view of the recent increase in fallout, which, to a large extent, comes from the 1958 tests (and which, of course, will be reduced gradually if atmospheric tests are not resumed), and of the fact that the contribution of carbon-14 was not considered in the earlier report, estimates of the amounts of radiation from fallout are increased. On the other hand, the fact that the earlier estimates of genetic damage from fallout were based on data from acute rather than chronic irradiation means that the effect of a given amount of fallout, or other radiation delivered at low rate, may be less than was previously estimated. It should be emphasized that estimates of human hazards continue to be based largely on data from mice.

Because of the finding that genetic effects per unit of radiation dose received at a low dose rate might be less than previously estimated, the Committee has reconsidered its earlier recommendation. It is presumably safe to conclude that the estimates of the genetic effects of fallout radiation and of other radiation at similar low intensities should now be based on mutation rates at least as low as those found with chronic irradiation of mice. However, the majority of the man-made radiation to which the population of the United States is exposed involves dose rates not yet adequately investigated experimentally. For example, we do not know whether the effects of low doses given at high dose rates, as in medical exposures, will be more like the response from acute irradiation or more like that from chronic irradiation. In the future, it may be desirable to relate maximum permissible exposures to dose rate as well as to total dose. But before this can be done, more information is needed at additional radiation intensities and for fractionated exposures. In the absence of such information, the Committee continues to recommend that for the general population, the average gonadal dose accumulated during the first thirty years of life should *not* exceed 10 r of man-made radiation, and should be kept as far below this as is practicable. This is in essential agreement with the most recent suggestion of the International Commission on Radiological Protection.

The medical and dental professions are commended for their continuing efforts to reduce diagnostic and therapeutic radiation exposures to the lowest levels consistent with sound medical and dental practice. At the same time, it is urged that further steps be taken to improve medical, census, and other records, including those of radiation exposures, in ways that will make them more useful than they now are for investigations of the genetic and other effects of radiation, as well as for studies of human genetics in general.

Future studies of mutagenesis must not be confined to radiation. Man is now exposed to an exceedingly complex environment and many agents may act to induce mutations. Among these agents may be mentioned industrial effluents, food additives, drugs, antibiotics, hormones, cosmetics, and contraceptive agents. Chemical mutagens (or antimutagens) are of particular interest since recent studies indicate that radiation may act through chemical products.

Much of the needed information must come from studies of a variety of animal species. Eventually, however, the results must be related to man. For this purpose, every use must be made of human populations that have been exposed to man-made radiation.

Some considerations that arise in human populations have no counterpart in animal societies. For example, human society depends upon a diversity of performance among its members and on very high mental qualities among a few of them. A human civilization might collapse by becoming qualitatively inadequate, even though reproductive selection of certain kinds were acting at high intensity and the number of individuals in the population remained at a level that was previously optimal.

The Committee urges that the effort in basic genetic research be increased. Use must be made of all the techniques of modern chemistry to improve our understanding of the basic genetic material and its reactions. Viruses, bacteria, fungi, algae, protozoa, as well as higher forms of plants and animals must be studied.

It is most important that able investigators be given adequate facilities, a stimulating research environment, and reasonable assurance of continued support. It is important that the medical profession become more familiar with the heritable diseases of man. Genetic training either in or prior to medical school should be increased.

Pathologic Effects

The Committee on Pathologic Effects of Atomic Radiation has conducted an extensive review of all pertinent data appearing since the 1956 report[3]. Some of the effects reported are small, and confirmation will be necessary before they can be either accepted or rejected. Although the general features of radiation-induced pathology are quite similar in animals and in man, each species has some unique peculiarities of response. Thus, all experimental data, even if completely established in animals, are not directly transferable to man.

Overall effects of overexposure will be determined to a considerable extent by the rate at which radiation overexposure takes place. When whole-body exposure is received at a high rate, as in the Japanese atomic bomb casualties and in some accidents, early clinical effects indicate injury to the blood-forming tissues and the intestinal tract. These tissues have great powers of recovery from injury, however, and this fact alters the response to low-level overexposures, continued over long periods of time. Under these conditions, a variety of effects are seen, including leukemia and skin cancer.

In animals, it has been established that a shortening of lifespan may result from radiation exposure. In general, for a constant dose rate, the amount of life shortening increases as the radiation dose is increased. For a constant total radiation dose, the amount of life shortening increases as the dose rate is increased. There is evidence that the amount of life shortening depends upon many factors, such as genetic makeup, age, and physical condition at the time of exposure.

It should be noted that these effects have been found in animals. Life shortening has not been demonstrated in man following small doses of radiation.

A life shortening effect in man is to be expected after substantial doses of whole-body radiation. This expectation comes from the results of animal experiments and from the fact that such exposures increase the incidence of leukemia in human populations. There are no studies adequate to permit an estimate of the magnitude of the life shortening effect in man. Present data cannot confirm or deny the existence of a threshold, below which no life shortening effect would be expected. The effects of dose, dose rate, and dose fractionation on life shortening are not known.

An increased incidence of leukemia, a relatively rare disease in man, has been found in population groups such as atomic bomb casualties or those chronically overexposed. Some studies have suggested an increased incidence of leukemia in children who have received prenatal diagnostic X-radiation. Other studies have failed to confirm this relationship, and it cannot be considered to be established at the present time.

Cataracts in man have resulted from overexposure of the eyes to X-rays, gamma rays, beta particles, or neutrons. The threshold for cataract production is 600-1000 r of 200 kv X-rays. On the basis of absorbed energy, neutrons are 5 - 10 times as effective in producing cataracts.

Small chronic radiation overexposure results in a gradual reduction in number, motility, and viability of sperm. This is one of the most sensitive known indicators of chronic biological damage. In dogs, effects on sperm have been observed at chronic dose rates only ten times

[3] NAS—NRC Publication 452, 1956.

the maximum permissible value for human occupational exposure. Limited human experiences suggest, but do not prove, that a single dose, even if it is a large fraction of the mid-lethal, does not have a serious permanent effect on fertility.

Large doses of radiation are known to produce serious injury to the central nervous system. Subtle changes in brain function have been reported following doses of only a few roentgens, but these effects cannot be considered established.

The development of mammalian embryos can be altered by radiation. In animals, doses of 100-300 r produce a series of malformations which depend on the state of embryonic development at the time of exposure. Little is known about effects in man following early irradiation. Embryonic irradiation appears to produce death or malformation in a dose range comparable to that required in other mammals.

An increased number of deaths with congenital malformations has been reported, associated with particular types of geological formations. No relationship between the number of these deaths and natural radiation background has been established.

Several lines of investigation are aimed at increasing knowledge of the factors which influence radiation sensitivity. Age at time of irradiation is known to be one factor. Age-sensitivity relationships are complicated and appear to depend upon species.

Inbred strains of mice seem to show two injury components in life shortening. One of these components is non-specific, the other is dependent on genetic makeup. It is not clear how these effects can be applied to a genetically heterogeneous human population. The presence of an ethnic factor in the incidence of leukemia suggests that genetic composition will play a role in susceptibility to radiogenic leukemia.

There is experimental evidence showing that radiation-induced tumors do not begin to develop immediately after the radiation has been absorbed. The malignant change ordinarily [illegible]s place after a series of precancerous changes, or tissue disorders. This disorder need not be [illegible] the site of the cancer.

There has been much discussion about a possible proportionality between radiation dose [illegible]d tumor incidence, and also about the existence of a threshold for tumor production. Defini-[illegible] experimental evidence is lacking and the Committee does not consider it justifiable to predict human tumor incidence at low doses from the incidences observed after high doses.

A similar situation exists for radiogenic leukemia. The Japanese data show that the incidence of myeloid leukemia is increased after a single, whole-body dose of radiation. In the dose range where an effect can be demonstrated, the increased incidence is about one case per year per million people for each rad of dose. There has been no significant increase in the leukemia rate since 1945 among the Japanese who presumably received from 50 to 100 rads. This observation does not, however, confirm or deny the existence of a dose threshold for leukemia production.

Radiation exposure from fallout arises from radioactive materials entering the body and from penetrating radiations from external sources. A group of Marshall Islanders and some Japanese fishermen were subjected to relatively heavy fallout. Both of these groups showed that internally deposited materials may barely exceed permissible levels while the dose from associated external radiation is high.

World-wide levels of radioactive strontium and iodine have increased but are still low. Each of these isotopes concentrates outside of the reproductive system and so genetic damage from them is small.

No completely satisfactory treatment of radiation injury has been developed. Antibiotics and properly timed blood transfusions have some beneficial effects. Bone marrow transfusions may have value in treating an acute overexposure.

Meteorological Aspects

Considerable progress has been made during the past three years toward a better understanding of the behavior of airborne radioactive contaminants arising either from nuclear detonations or as effluents from nuclear reactors. The present report deals primarily with the meteorological aspects of world-wide, or delayed, fallout.

It has recently been proposed that nuclear explosions be used for meteorological research but such use seems unwarranted. No new evidence has appeared to show that the weather has been affected by nuclear testing.

At the present time, delayed fallout from the stratospheric reservoir is the major source of airborne artificial radioactivity. This will continue to be the case unless large-scale testing is resumed. The most important isotopes in this debris are strontium-90 and cesium-137, existing as particles less than 0.1 micron (39 millionths of an inch). Carbon-14 also exists both as carbon dioxide and as carbonates.

Networks for sample collection and analysis have become widespread, so the important features of world-wide fallout are now known. Free air samples have been obtained systematically at several locations and at altitudes up to 90,000 ft. Although conditions in the stratosphere are not well understood, a considerable fund of information now exists on the large scale distribution of debris in it. Some progress has been made in studying fallout over water, but mixing with deep layers makes interpretation difficult.

The non-uniform distribution of strontium-90 suggested in 1956 has been confirmed, and an estimate of conditions in 1962-1963 from present sources is now made. The maximum concentration occurs at 40-50°N latitude. Strontium-90 fallout is greatest in the spring and lowest in the fall. Most fallout is brought down by precipitation.

Some recent progress has been made in determining the residence time of debris in various parts of the atmosphere. This time is important because it determines the amount of radioactive decay that takes place before particles return to the surface of the earth. The half-residence time (the time required to remove one-half of that originally present) is about two to four weeks in the troposphere. Conditions in the stratosphere are more complicated and half-residence time cannot be generally used. When the debris enters the stratosphere at the equator, half-residence times range from one to five years. Debris entering in the temperate or polar regions will have a half-residence time of less than one year.

Reasonable assumptions suggest that 3.0 million curies of strontium-90 had fallen out as of November, 1958, and that about 2.5 million curies remained in the stratosphere. Most of this will be down by 1962-1963. At this time, the ground concentrations will be about twice those of November, 1958, if there are no further additions to the atmospheric burden.

Predictions of future carbon-14 resulting from past atomic tests are more difficult because of uncertain mixing with ocean waters. A maximum carbon-14 concentration in air no greater than about 70 percent above that occurring naturally is expected in a few years. Mixing with ocean waters should reduce this to about 30 percent of natural carbon-14 background in a few decades. Eventually this concentration will be reduced to 1 percent or less of the natural background.

Agriculture and Food Supplies

The Committee has reviewed developments relating radiation and radioisotopes to agriculture and food supplies, and reaffirms its earlier conclusion that their main impact and contributions are coming through acceleration in the progress of agricultural research. The use of radioisotopes as tracers has continued to grow, and is increasing our understanding of the basic chemical and biological events involved in crop and animal husbandry. In particular, the use of carbon-14 and more recently hydrogen-3 (tritium) has been rewarding. There is still much potential for further applications of tracer techniques in research.

The production of radiation-induced mutants of plants has placed a new tool in the hands of plant breeders, supplementing but not displacing conventional crop improvement methods. So far, very few new varieties developed from radiation-induced mutants have been released and accepted by farmers. With the possible exception of poultry, there seems little hope of genetic improvements in farm animals through radiation-induced mutants.

In the past, the use of radioisotopes for studies of nutrition or basic physiology in large animals has been restricted because of problems of ultimate disposal of the experimental animals. Procedures have now been established and published for determining the acceptability of meat from animals that have received tracer amounts of radioisotopes. These procedures, which fully protect the public welfare, were established by the Meat Inspection Division of the Agriculture Research Service, U. S. Department of Agriculture, in consultation with the Food and Drug Administration.

Following a pilot experiment on the island of Curaçao, an attempt was made to control the damaging screw worm in the Southeastern United States. Male flies sterilized by radiation were released in January, 1958, in Florida, and these were followed by releases in Georgia and Alabama. At the end of 1959, many months had elapsed with only a single report of screw worm damage. This technique is not applicable to many insect pests, but attempts are being made to extend its use to other insects that might be responsive to control by these means.

Research on the use of radiation to preserve foods has continued. Some of the advantages of radiation preservation are of more importance to the military than to the civilian consumer. Problems of flavor, odor, texture, nutritive value, etc., remain to be solved before widespread civilian acceptance can be expected. There must be additional studies of the wholesomeness of irradiated foods consumed for long periods of time.

During the past three years, there has been much concern about the consumption of plant and animal products which have accumulated radioactive fission products from soil or vegetation. This concern has been heightened by the apparent disagreement among scientists. Much of the disagreement arises from the lack of necessary information. In the absence of information, long-range extrapolations or predictions have been made from presently available sketchy data. In this process, various sets of assumptions have led to a variety of conclusions. New data will reduce present uncertainties and lead to closer agreement on future effects.

The radioisotope levels currently present in foodstuffs are so low that they are only measurable by highly sensitive instruments. Analyses are expensive in time and equipment; routine examination or monitoring of all foods is not currently feasible. Although the present levels in foodstuffs are low, it is the cumulative and retained isotope burden in man that must be considered. It is certain that all living things, man included, now have a radioactive body burden higher and different from that of the pre-atomic era. The significant long-range effects of the presence of these radioactive elements remains to be determined.

Substantial progress has been made at the technical level toward understanding the mechanisms involved in entry and uptake of fallout elements into plants, their accumulation in those parts used for food by animals and man, and their retention and distribution in animals and man. Fallout deposition in areas of agricultural production is non-uniform with the result that the radioisotope level of similar crop or animal products from different locations varies considerably. This is a matter of concern in view of our current inability to monitor all foods or food ingredients.

Disposal and Dispersal of Radioactive Wastes

The expanding uses of nuclear energy inevitably produce increasingly large amounts of radioactive wastes. Unlike most industrial wastes, radioactivity cannot be rendered harmless by altering its form or composition. There has been an increasing public interest in all sources of potential radiation exposure. In response to this interest, several committees of the United States Congress held extensive hearings during 1959 on all phases of radioactive waste disposal.

To appreciate the implications of the controlled release of radioactivity to our environment, the public must have a broad understanding of the hazards involved. This understanding must go beyond radioactivity itself to include the concepts of concentration, total quantity, isotopic composition, and chemical and physical nature.

The sequence of events by which dispersed materials might come in contact with human populations must be traced with sufficient reliability to permit an accurate evaluation of the behavior of these materials in man's environment including food chains.

Three of the major factors in waste disposal are:

1. the maximum quantity of each pertinent isotope allowable in the human body or in the critical organ,

2. the specific nature of the waste products, and

3. the physical, chemical, and biological properties of the environment into which the waste is released.

Proper waste management requires that operations under restrictions 2 and 3 result in situations compatible with the standards established in 1.

To date, radioactive waste operations have not resulted in any significant effect on the public, its environment, or its natural resources. Energetic monitoring programs must be maintained to insure a continuation of this status.

Methods have been developed for the removal of major portions of the activity from many low-level wastes so that large volumes of liquids can be safely discharged to the environment. Existing treatment systems have satisfactorily handled intermediate-level wastes.

High-level wastes are produced primarily during the chemical processing of spent reactor fuels. About 65 million gallons of these wastes are now held in underground tanks at AEC storage sites. It is generally agreed that tank storage is not the ultimate solution to the waste problem, but will always form a part of any disposal system.

Normal power reactor operations have not presented major waste disposal problems to date. Present plans call for the transportation of used fuel elements to AEC reprocessing facilities. Neither ground disposal nor the dilution capacity of streams is included in present planning for the disposal of liquid wastes from large power reactors now under design or construction.

Many investigations are under way to improve methods of treatment and disposal of highly radioactive wastes. Procedures under investigation include (1) immobilization of fission products in solids, (2) storage of these solids in selected geologic formations, and (3) direct discharge of liquids in selected geologic strata.

Solid wastes are presently disposed of by land burial at AEC sites or by burial at sea. With increasing waste volumes, and the geographic spread of the use of radioactive materials, permanent land burial sites are needed in various parts of the country. Many administrative, legal, and public relations problems must be faced in organizing land burial programs.

Some United States practice has deposited solid, packaged wastes in the ocean. The safety of these operations has been supported by (1) the views of experts in the marine sciences and related fields, (2) the operating experiences of the British with considerably greater quantities of liquid wastes, and (3) preliminary field studies in the Atlantic and Pacific disposal areas.

Airborne radioactive effluents presented serious control problems in the past, but a variety of methods have been developed to cope with them. Further developments will be needed to permit more radical reactor operations, and to deal with abnormal operating situations.

There is an increasing number of shipments of radioactive materials in a wide variety of amounts, by all common modes of transport. Federal regulations apply to interstate shipments. Some states and municipalities are adopting local transport regulations.

Although the total cost for radioactive waste disposal is high, it does not appear to be a limiting factor in the development of nuclear power. If economic power from nuclear fission is not obtained, it will not be due to the costs of waste management.

It seems realistic to estimate future liquid waste volumes from an assumed nuclear power output of 100,000 thermal megawatts in 1980. This power level will lead to about 36 million gallons of highly radioactive wastes by 1980. This is less than the amount now in storage from the operations to date of the United States atomic energy program. Improved fuel reprocessing technology may enable substantial reductions in the volume of such wastes produced in the future.

Radioactive waste disposal affects all mankind, and close agreement and cooperation will be needed on state, national, and international levels. Careful planning and constant vigilance will be required, but there is nothing inherent in the waste control problem to restrict the nuclear energy program, with adequate protection of public health and safety.

Oceanography and Fisheries

Since its 1957 report[4], this Committee has taken on additional responsibilities by functioning as a subcommittee of the Committee on Oceanography of the National Academy of Sciences.

Three published reports by this group have presented detailed discussion on (1) the disposal of low-level radioactive wastes off the Atlantic and Gulf coasts of the United States[5], (2) radioactive wastes from nuclear-powered ships[6], and (3) recommended research and monitoring programs[7]. A report in preparation will consider radioactive waste disposal off the Pacific coast of the United States.

In the report on low-level disposal, several locations were suggested, each of which appeared capable of accepting safely 250 curies of strontium-90 or its equivalent annually. More detailed studies of each area prior to starting disposal operations were recommended.

In studying radioactive waste disposal from nuclear-powered ships, five subdivisions of the entire marine environment were considered. These ranged from harbors and estuaries to the open sea outside of fishery areas. The corresponding maximum radioactive concentrations recommended ranged from one to twenty-five times that allowed for drinking water.

A comprehensive research program must emphasize studies of estuaries, coastal waters, and the high seas. Estuaries and coastal waters are variable in both space and time and so

[4] NAS—NRC Publication 551, 1957.
[5] NAS—NRC Publication 655, 1959.
[6] NAS—NRC Publication 658, 1959.
[7] Chapter V of "Oceanography 1960 to 1970," 1959.

several must be studied if generalizations are to be attempted. Oceanographic pollution involves a complex of physical, chemical, and biological factors. Detailed knowledge of all will be needed to plan disposal programs with complete assurance.

Part of the Congressional hearings on Industrial Radioactive Waste Disposal was devoted to oceanographic problems. The Congress has shown an interest in providing federal support for oceanographic research, and authorizing legislation has been introduced.

In the future, wastes resulting from a wide variety of peacetime uses will probably become the chief source of radioactivity added to the oceans. Future sources will include normal and abnormal operation of nuclear power plants, laboratories, industry and hospitals, large-scale tracing experiments, and perhaps nuclear detonations for peaceful purposes.

There are sharp differences of opinion among oceanographers and marine biologists on the handling of maritime resources. Some feel that no radioactive wastes should be introduced into the oceans; others see no human harm resulting from the disposal of considerable quantities. This Committee believes that these differences can be resolved by adequate programs of research and education.

This Committee has previously estimated maximum allowable concentrations of a variety of radioactive nuclides in sea water. Recalculations based on a more detailed analysis yield some values lower than before. On the other hand, the value for strontium-90 is raised to about 30 times the concentration allowable for drinking water. Because of concentration by marine life, some of the calculated values fall below those allowed for drinking water.

Relatively detailed information is now available from two large-scale disposal operations. The British have very carefully monitored their disposal of reactor wastes directly into the Irish Sea. From these measurements, they have raised their estimates of the amount of material safely disposable at this site to 100,000 curies per month. The actual discharges reported are well below this figure.

Operations at Hanford release about 2000 curies per day of neutron activation products to the Columbia River. Monitoring data taken downstream from the point of entry show that the exposure of persons eating fish caught in the river is below permissible limits. Although these experiences are encouraging, each discharge situation will be unique. Comprehensive monitoring programs must be carried out wherever there is a substantial amount of activity introduced into water.

Present information indicates that limited quantities of radioactive materials can be safely released into the oceans. These releases might be for scientific or engineering purposes, or might be low-level waste products. All releases must be properly supervised and monitored to insure public health and to protect marine resources.

It is premature to decide whether any high-level wastes can or should be disposed of at sea.

Adequate records of all disposals should be kept on a national scale. These records should be available to those interested and should be disseminated on an international scale.

All pertinent facts, areas of agreement and of disagreement, and ultimate goals should be made public. While some of the problems are disturbing and difficult, all are subject to rational attack. Educational programs must be aimed at individuals, states, and nations.

III. CONCLUSIONS

Developments since the 1956 report indicate clearly that radiation in all its forms will play an increasing role in the lives of all mankind. The uses of nuclear fission will continue to expand and potential radiation hazards will increase accordingly. Unlike most other hazards, radiation exposure can adversely affect many future generations. The need for conservative management of all radiation sources is obvious.

In general, the potential hazards associated with radiation sources are being recognized by an increasing number of those responsible for their operation. A large section of management has been conservative and has protected the public interest.

There are still many unknowns, and research on a wide front is urgently needed. As new information is gained, man can expect to derive increasing benefits from the release of nuclear energy with a minimum hazard to himself and his descendants.

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G. Failla, Columbia University
Alexander Hollaender, Oak Ridge National Laboratory
Berwind P. Kaufmann, Carnegie Institution of Washington, Cold Spring Harbor, L.I., N.Y.
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W. L. Russell, Oak Ridge National Laboratory
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Shields Warren, New England Deaconess Hospital, Boston
Sewall Wright, University of Wisconsin

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Consultants:

LYLE T. ALEXANDER, U. S. Dept. of Agriculture, Beltsville, Maryland
I. H. BLIFFORD, JR., Aeronutronic Systems, Inc., Glendale, California
JOHN H. HARLEY, USAEC New York Operations Office
J. Z. HOLLAND, USAEC Div. of Biology and Medicine
H. HOLLISTER, USAEC Div. of Biology and Medicine
CHRISTIAN E. JUNGE, Air Force Cambridge Research Center, Bedford, Mass.
MARVIN KALKSTEIN, Air Force Cambridge Research Center, Bedford, Mass.
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Consultants:

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