THE BIOLOGICAL EFFECTS OF ATOMIC RADIATION

SUMMARY REPORTS

1960

National Academy of Sciences—

National Research Council

THE BIOLOGICAL EFFECTS OF ATOMIC RADIATION

SUMMARY REPORTS

From a Study by the

NATIONAL ACADEMY OF SCIENCES

NATIONAL ACADEMY OF SCIENCES — NATIONAL RESEARCH COUNCIL
Washington
1960

FOREWORD

IN JUNE 1956 the National Academy of Sciences published the first summary reports of the findings and recommendations of six committees established to study the biological effects of atomic radiations. These committees cover the fields of genetics, pathology, meteorology, oceanography and fisheries, agriculture and food supplies, and the disposal and dispersal of radioactive wastes.

During the intervening years the committees have continued to work on various aspects of their several fields, gathering additional information, reviewing new findings as research has advanced, and identifying fruitful lines for further exploration.

Last autumn it appeared that the time was again at hand for concerted consideration of the over-all question of biological effects, with a view to the preparation of new summary reports to bring the findings of the committees up to date. Those summaries are contained in the present volume.

A general conclusion from the reports of all six committees is that the steady accumulation of scientific information since 1956 has not brought to light any facts that call for drastic revisions of their earlier recommendations. It will be noted by those familiar with the previous publication that in their new reports the committees have in general devoted greater attention to future objectives in the study of biological hazards and to research programs that are needed to attain them.

As was the case in 1956, the summary reports will be followed by reports in detail on a number of special problems.

Members of the committees, together with their panels and consultants, number more than 140 distinguished scientists. To them the special appreciation of the National Academy of Sciences is due. They have given unsparingly of their time and energies to elucidate the scientific facts and issues bearing on the questions before them. In doing so they have served without compensation, and as individuals rather than representatives of their institutions, companies, or governmental agencies.

Howard L. Andrews, Head of the Radiation Physics Section of the National Cancer Institute, has given exceptional service on behalf of the Academy as coordinator and staff director of these summary studies. We are indebted to the Director of the National Institutes of Health for making Dr. Andrews' services available. It is a pleasure also to acknowledge the sustained and wholehearted cooperation of administrators and scientists of the Atomic Energy Commission, other governmental agencies, and a number of academic institutions. We are grateful for the continued financial support of The Rockefeller Foundation in our general studies of the biological effects of atomic radiations.

DETLEV W. BRONK, *President*
National Academy of Sciences

May 1960

CONTENTS

	Page
FOREWORD	iii
MEMBERSHIP OF COMMITTEES	vii
REPORTS OF COMMITTEES	
GENETIC EFFECTS	
I. Our present position	3
II. Responsibilities of geneticists	4
III. What we need to know	6
1. Mutation	8
2. Phenotypic effects	11
3. The behavior of genes in populations	12
4. Basic research	13
IV. How to expedite needed research	14
1. Genetics in medical schools	15
2. The utilization of medical records	15
3. Census data and human genetics	16
4. The support of basic genetic research	16
5. The manpower problem	17
6. Continuity of support	17
On the Appraisal of Genetic Effects of Radiation in Man, *by Sewall Wright*	18
PATHOLOGIC EFFECTS	27
App. A. Interim statement of Subcommittee on Acute and Long-Term Hematological Effects	34
App. B. Interim statement of Subcommittee on Inhalation Hazards	36
METEOROLOGICAL ASPECTS	
I. Preface	41
II. Introduction to the fallout problem	41
III. Recent observations	42
IV. Analysis and interpretation	43
V. Future fallout	45
VI. Conclusions	46

Page

AGRICULTURE AND FOOD SUPPLIES

I. Introduction 49
II. Radiation in agricultural research 49
III. Tracer studies 49
IV. Evaluation of research 50
V. Radiation and plant mutations 50
VI. Radioisotopes for physiological research 50
VII. Control of insect pests 51
VIII. Food processing 51
IX. Fallout on soil and vegetation 51

DISPOSAL AND DISPERSAL OF RADIOACTIVE WASTES

I. Introduction 57
II. Present status of radioactive waste disposal 59
III. Problem areas now under investigation 60
IV. The cost of radioactive waste management 64
V. Magnitude of future waste management problem 64
VI. Federal-state relationships 65
VII. International aspects 65
VIII. Effects of waste management operations on man's overall radiation exposure 66

OCEANOGRAPHY AND FISHERIES

I. Introduction 69
II. Conclusions and recommendations 72
III. Summary of recent developments 74
1. Recommendations concerning the disposal of packaged low-level wastes along the Atlantic, Gulf, and Pacific coasts 74
2. Recommendations concerning the disposal of wastes from nuclear-powered vessels 75
3. Suggested methods of calculation of the permissible concentrations of radioactive isotopes in sea water 76
4. Research recommendations 82
5. Radioactive materials introduced into the Irish Sea and the Columbia River 84
6. Recent developments in our knowledge of the deep sea and in field measurement techniques 86
IV. References 88

MEMBERSHIP OF THE COMMITTEE ON GENETIC EFFECTS OF ATOMIC RADIATION

GEORGE W. BEADLE, California Institute of Technology, *Chairman*
H. BENTLEY GLASS, Johns Hopkins University, *Rapporteur*
JAMES F. CROW, University of Wisconsin
M. DEMEREC, Carnegie Institution of Washington, Cold Spring Harbor, L.I., N.Y.
THEODOSIUS DOBZHANSKY, Columbia University
G. FAILLA, Columbia University
ALEXANDER HOLLAENDER, Oak Ridge National Laboratory
BERWIND P. KAUFMANN, Carnegie Institution of Washington, Cold Spring Harbor, L.I., N.Y.
H. J. MULLER, Indiana University
JAMES V. NEEL, University of Michigan
W. L. RUSSELL, Oak Ridge National Laboratory
A. H. STURTEVANT, California Institute of Technology
SHIELDS WARREN, New England Deaconess Hospital, Boston
SEWALL WRIGHT, University of Wisconsin

MEMBERSHIP OF
THE COMMITTEE AND SUBCOMMITTEES ON
PATHOLOGIC EFFECTS OF ATOMIC RADIATION

Committee Members:

SHIELDS WARREN, New England Deaconess Hospital, Boston, *Chairman*
HOWARD L. ANDREWS, National Institutes of Health
HENRY A. BLAIR, University of Rochester
AUSTIN M. BRUES, Argonne National Laboratory
JOHN C. BUGHER, Rockefeller Foundation
RICHARD H. CHAMBERLAIN, University of Pennsylvania
EUGENE P. CRONKITE, Brookhaven National Laboratory
CHARLES E. DUNLAP, Tulane University
JACOB FURTH, Roswell Park Memorial Institute, Buffalo
WEBB HAYMAKER, Armed Forces Institute of Pathology, Washington
LOUIS H. HEMPELMANN, University of Rochester
SAMUEL P. HICKS, New England Deaconess Hospital, Boston
HENRY S. KAPLAN, Stanford University, Palo Alto
HARRY A. KORNBERG, General Electric Company, Richland, Washington
SIDNEY C. MADDEN, University of California at Los Angeles

Subcommittee on Acute and Long-Term Hematological Effects

EUGENE P. CRONKITE, Brookhaven National Laboratory, *Chairman*
VICTOR P. BOND, Brookhaven National Laboratory
JAMES B. HARTGERING, Army Research Office, Washington
MARYLOU INGRAM, University of Rochester
GEORGE V. LEROY, University of Chicago
WILLIAM C. MOLONEY, Boston City Hospital
CARL V. MOORE, Washington University, St. Louis
ROBERT D. MOSELEY, JR., University of Chicago
JOHN H. RUST, University of Chicago
MARVIN SCHNEIDERMAN, National Institutes of Health
FREDERICK STOHLMAN, JR., National Institutes of Health
CARL F. TESSMER, Armed Forces Institute of Pathology, Washington

Subcommittee on Internal Emitters

AUSTIN M. BRUES, Argonne National Laboratory, *Chairman*
THOMAS F. DOUGHERTY, University of Utah
MIRIAM P. FINKEL, Argonne National Laboratory

HYMER L. FRIEDELL, Western Reserve University
WRIGHT B. LANGHAM, Los Alamos Scientific Laboratory
KERMIT H. LARSON, University of California at Los Angeles
HERMANN LISCO, Argonne National Laboratory
WILLIAM P. NORRIS, Argonne National Laboratory
J. NEWELL STANNARD, University of Rochester
JOSEPH D. TERESI, U. S. Naval Radiological Defense Laboratory, San Francisco
ROY C. THOMPSON, General Electric Company, Richland, Washington
RAYMOND E. ZIRKLE, University of Chicago

Subcommittee on Inhalation Hazards

HARRY A. KORNBERG, General Electric Comany, Richland, Washington, *Chairman*
W. J. BAIR, General Electric Company, Richland, Washington
STANTON H. COHN, Brookhaven National Laboratory
C. C. GAMERTSFELDER, General Electric Company, Cincinnati
J. W. HEALY, General Electric Company, Richland, Washington
FRANCIS R. HOLDEN, Radiation Detection Company, Palo Alto
JAMES K. SCOTT, University of Rochester
J. NEWELL STANNARD, University of Rochester
GEORGE V. TAPLIN, University of California Medical Center, Los Angeles

Subcommittee on Permanent and Delayed Biological Effects of Ionizing Radiations from External Sources

HENRY A. BLAIR, University of Rochester, *Chairman*
GEORGE W. CASARETT, University of Rochester
JOHN B. HURSH, University of Rochester
ROBERT W. MILLER, University of Michigan
THOMAS R. NOONAN, University of Rochester
ROBERTS RUGH, Columbia University
GEORGE A. SACHER, Argonne National Laboratory
JAMES K. SCOTT, University of Rochester
LAWRENCE W. TUTTLE, University of Rochester
ARTHUR C. UPTON, Oak Ridge National Laboratory

MEMBERSHIP OF THE COMMITTEE ON METEOROLOGICAL ASPECTS OF THE EFFECTS OF ATOMIC RADIATION

HARRY WEXLER, U. S. Weather Bureau, *Chairman*
LESTER MACHTA, U. S. Weather Bureau, *Rapporteur*
CHARLES E. ANDERSON, Air Force Cambridge Research Center, Bedford, Mass.
R. R. BRAHAM, JR., University of Chicago
MERRIL EISENBUD, New York University
D. LEE HARRIS, U. S. Weather Bureau
B. G. HOLZMAN, Office of Scientific Research, U. S. Air Force
H. G. HOUGHTON, Massachusetts Institute of Technology
W. W. KELLOGG, The Rand Corporation, Santa Monica
HEINZ LETTAU, University of Wisconsin
ROBERT J. LIST, U. S. Weather Bureau
N. M. LULEJIAN, COL., Air Research and Development Command, U. S. Air Force, Inglewood, California
E. A. MARTELL, Air Force Cambridge Research Center, Bedford, Mass.

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.
W. F. LIBBY, University of California, Los Angeles
L. B. LOCKHART, JR., U. S. Naval Research Laboratory
R. H. NEILL, Div. of Radiological Health, USPHS
R. L. PATTERSON, JR., U. S. Naval Research Laboratory
W. SINGLEVICH, Hq., U. S. Air Force (AFTAC)
JEROME SPAR, New York University
JAMES G. TERRILL, JR., Div. of Radiological Health, USPHS
A. K. STEBBINS, USAF Defense Atomic Support Agency, Washington

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

A. G. Norman, University of Michigan, *Chairman*
C. L. Comar, Cornell University
George W. Irving, Jr., U. S. Department of Agriculture, Washington
James H. Jensen, Iowa State University
J. K. Loosli, Cornell University
R. L. Lovvorn, North Carolina State College
Ralph B. March, University of California, Riverside
George L. McNew, Boyce Thompson Institute for Plant Research, Yonkers, New York
Roy Overstreet, University of California, Berkeley
Kenneth B. Raper, University of Wisconsin
H. A. Rodenhiser, U. S. Department of Agriculture, Beltsville, Maryland
W. Ralph Singleton, University of Virginia
Ralph G. U. Siu, Office of the Quartermaster General, Washington
G. Fred Somers, University of Delaware
George F. Stewart, University of California, Davis

MEMBERSHIP OF THE COMMITTEE ON DISPOSAL AND DISPERSAL OF RADIOACTIVE WASTES

ABEL WOLMAN, Johns Hopkins University, *Chairman*
J. A. LIEBERMAN, U. S. Atomic Energy Commission, *Rapporteur*
F. L. CULLER, JR., Oak Ridge National Laboratory
A. E. GORMAN, Ormand Beach, Florida
L. P. HATCH, Brookhaven National Laboratory
H. H. HESS, Princeton University
C. W. KLASSEN, Illinois State Department of Health
SIDNEY KRASIK, Westinghouse Atomic Power Division
H. M. PARKER, General Electric Atomic Energy Project, Hanford
WALTER A. PATRICK, Johns Hopkins University
SHEPPARD T. POWELL, Consulting Engineer, Baltimore
LESLIE SILVERMAN, Harvard University
PHILIP SPORN, American Electric Power Service Corp., New York
CONRAD P. STRAUB, U. S. Public Health Service, Cincinnati
C. V. THEIS, U. S. Geological Survey, Albuquerque
F. WESTERN, U. S. Atomic Energy Commission, Washington

MEMBERSHIP OF THE COMMITTEE ON OCEANOGRAPHY AND FISHERIES

ROGER REVELLE, Scripps Institution of Oceanography, *Chairman*
DAYTON E. CARRITT, Chesapeake Bay Institute, Johns Hopkins University
WALTER A. CHIPMAN, U. S. Fish and Wildlife Service, Beaufort, N. C.
LAUREN R. DONALDSON, University of Washington
RICHARD H. FLEMING, University of Washington
RICHARD F. FOSTER, General Electric Company, Richland, Washington
EDWARD D. GOLDBERG, Scripps Institution of Oceanography
BOSTWICK KETCHUM, Woods Hole Oceanographic Institution
LOUIS A. KRUMHOLZ, University of Louisville
CHARLES E. RENN, Johns Hopkins University
MILNER B. SCHAEFER, Scripps Institution of Oceanography
ALLYN C. VINE, Woods Hole Oceanographic Institution
LIONEL A. WALFORD, U. S. Dept. of Interior, Fish and Wildlife Service
WARREN S. WOOSTER, Scripps Institution of Oceanography

Consultants:

THEODORE R. FOLSOM, Scripps Institution of Oceanography
ALLYN SEYMOUR, University of Washington

Report of the

COMMITTEE ON THE GENETIC EFFECTS

OF

ATOMIC RADIATION

REPORT OF THE

COMMITTEE ON GENETIC EFFECTS

I. Our Present Position

DURING the period elapsed 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 in which 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 are the most important cell stages as far as human hazards are concerned.

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 sex-linked lethals induced in oogonia 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 a 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, most 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 at 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 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.

The new findings have not changed the evaluations presented in 1956. These new developments do, however, emphasize the unique responsibility of geneticists to so stimulate and guide research that the urgently needed technical information is obtained as effectively and as promptly as possible.

II. Responsibilities Of Geneticists

The dramatic exploitation of nuclear energy for military and peacetime purposes has made informed persons acutely aware that man-made ionizing radiation, whatever its source, is now an important addition to a constantly changing list of hazards to human existence and well-being. Exposures from medical uses in technologically advanced nations are now about equal to background and need to be taken into account to a corresponding degree.

Insofar as the uses of nuclear energy add radioactive contaminants to the general environment of man, and especially to the atmosphere, important moral issues arise even though the magnitude of the radiation to the germ line is now small relative to natural background levels. These new uses make possible, for the first time in human history, the inescapable exposure of world populations, in some instances without consent, to additional radiation undetectable by the unaided human senses and capable of producing deleterious changes in the hereditary material.

Although it is not the special province of natural science by itself to say how these issues should be resolved, it is surely a grave and urgent responsibility of geneticists to make the best possible estimates of the magnitude of the genetic effects of small increments of ionizing radiation and to take action in adding to and improving the store of knowledge on which such estimates are based. Only in this way can the needed quantitative refinements be made in the rather crude estimates that have already been made.

The present state of knowledge, on which are based estimates of the genetic hazards of increased irradiation of man, has been summarized in reports of the British Medical Research Council's Committee on the Hazards to Man of Nuclear and Allied Radiations; by the World Health Organization's Committee on Effects of Radiation on Human Heredity; by this Committee; by other organizations and individuals; and especially by the recently published and extensively documented report of the United Nations Scientific Committee on the Effects of Atomic Radiation, a report prepared and approved by scientific representatives of all member nations. Reference is also made to the latest report of the International Commission on Radiological Protection, in which the problem of allowable genetic exposure of large populations to radiation is treated in some detail. It is recognized by all that present knowledge is not adequate to assess with any reasonable reliability the genetic consequences of specified levels of exposure.

The urgency of the practical problems of reactor design, disposal of radioactive wastes, testing of nuclear weapons, X-ray equipment design and manner of use, etc., has, however, made it essential that there be recommended some upper limit of exposure of large populations to radiation above normal background. Recognizing that from a genetic point of view there appears to be no threshold level of exposure below which genetic damage does not occur, this Committee has suggested—mainly on practical considerations—that the average population exposure to man-made ionizing radiation, including medical radiation, be no more than 10 roentgens to the gonads per reproductive cycle—preferably it should be less. The British Committee has made an essentially similar recommendation.

It is well appreciated that it will be some time and will require much work before this recommendation can be more adequately supported and perhaps modified. We urge that the required work be pursued as rapidly as possible. We further urge that, in the meantime, action in reducing all exposure of persons to the lowest practicable levels not be deferred, for it is unlikely that we shall have all the necessary information in the near future. In the absence of such information, there is much to be said for erring on the side of caution, considering that the genetic consequences of any increased exposure to mutagenic radiation will continue to be expressed in some degree for many generations to come.

It should be pointed out that if significant refinements in estimates of present and anticipated genetic hazards are to be made, corresponding refinements must be made in our knowledge of radiation exposures. As radiologists well recognize, we need much better information than we now have on gonadal exposures from various types of medically used radiations. This applies also to occupational exposures, especially to internal emitters. Background and fallout measurements need improvement and re-evaluation in the light of present and future activities involving radiation. Additional information is needed on the magnitude, distribution, and action of background, fallout, and other radiation to which man is exposed. This is especially urgent for those radionuclides, such as iodine, strontium, and radium, that accumulate or are concentrated in various parts of the body. While these are not studies in which geneticists would normally take an active part, they are nevertheless necessary in order to provide an essential part of the information needed by geneticists for the estimates they are expected to make.

A large and important area in which progress is being made at present and in which much more can be done in the immediate future is that of reducing human exposure to man-controlled radiation, including that from diagnostic and therapeutic medical radiation; that from industrial and other peacetime uses of nuclear energy; and that arising from development, testing, and use of nuclear devices. Although a consideration of how further reductions in exposure to radiation from such sources can most effectively and quickly be brought about lies largely outside the competence and assignment of this Committee, we nevertheless regard it as desirable and proper to urge that those who possess the requisite knowledge, persuasiveness, and authority continue to take all reasonable steps in bringing about such reduction as rapidly as possible and to the lowest practicable levels.

In this connection, it is noteworthy that the International Commission on Radiological Protection, in its latest report, has suggested a three-fold reduction of the maximum permissible gonad doses for occupational exposure. It has also recommended a maximum permissible genetic dose for the population in line with this Committee's recommendation of 1956, but in greater detail to provide additional safeguards. Also, the American College of Radiology has initiated an educational campaign to reduce the gonadal doses received by patients from diagnostic and therapeutic procedures.

It is the purpose of the present report to supplement the earlier report of this Committee in two ways: (1) by indicating some of the specific areas in which additional knowledge appears to us to be necessary for the desired refinements in estimates of probable genetic damage from radiation, and (2) by suggesting ways in which attainment of this knowledge can be expedited.

In indicating specific areas in which further research is needed, Committee members hope that the development of novel and more imaginative approaches will not be discouraged. We are well aware that some of the most important discoveries in the future will almost surely come from unexpected directions instead of from areas of research that can now be seen clearly. Nevertheless, since there are obvious gaps in our present knowledge that can be filled by application of existing or readily foreseeable methods, we have prepared this account of the major areas of needed investigation as seen from our present viewpoint.

III. What We Need To Know

The essential problems are: What are the characteristics and magnitude of the genetic effects of ionizing radiation on man, how important are these effects, and how can they be avoided or mitigated?

In order to characterize and better define present estimates of the magnitude of radiation-induced effects, further information will also be needed about the occurrence of spontaneous mutations and those caused by agents other than radiation. In order to assess radiation effects with more accuracy, we need to know more about the breeding structure of human populations, the detailed working of selection in them, and the effects of modern hygiene and therapeutic procedures. It will be necessary to answer many related questions about the somatic effects on man of radiation and other agents. We must learn more about the genetics of organisms other than man and about the effects of radiation on them. This is so because in many but not all respects—witness recent studies on human hemoglobin—basic genetics can best be studied in such organisms. It is inevitable that some of the most important conclusions that are applied to man will have to be derived in the first place from our basic knowledge of the effects of radiation on other organisms.

To determine the amount of exposure of human populations to radiation, further studies are needed of the dosages received by various parts of the body—especially the gonads—from such sources as medical, industrial, research, and military uses of radiation, whether these be external or internal to the body. It is also necessary to know the physical characteristics and the distribution in the body of the various types of radiation. And, although it is not for this Committee to say how we might best attain it, we need further knowledge of the ways in which dosages may be reduced without sacrificing important economic gains and the advantages derived from the proper use of medical radiations in diagnosis and therapy.

To determine the consequences of radiation exposure for present and future generations, information at many levels is needed. Investigations designed to obtain such information may be classified under two general headings, though many individual projects may come under both, or fall between.

1. Investigations needed for early improvement in estimates of radiation exposures from given practices and their consequences. These are obviously necessary as a basis for wise policy decisions.

2. Studies designed to extend our fundamental knowledge of mutation and mutant effects, and to indicate ways in which this knowledge can be used in arriving at improved estimates of radiation damage to be expected from given levels of radiation.

For the first group of projects there is obvious need for a more nearly adequate definition of the social burden due to genetic damage. This requires estimates of the amount of harm done by various human abnormalities and the determination of the extent to which these are genetic in origin. The latter can be estimated by pedigree analysis, by studies of twins and foster children, and by studies of children of consanguineous marriages.

Estimates of the extent to which radiation-induced mutation adds to the social burden can be obtained in various ways, among them: further analysis of the descendants of human groups who have for one reason or another been exposed to doses of ionizing radiation much higher than average, and comparison with appropriately chosen controls; studies of mutation rates at specific loci and total rates for broad classes of mutations (e.g., lethals) in mammals of various lengths of life cycle; and studies of fecundity, growth, sex ratio, development, mortality, and behavior in the descendants of mammals exposed to ionizing radiation. Such studies should compare chronic and acute radiation dosages, they should include radiation given over a single generation and over successive generations, and they should estimate the effects of differing levels of inbreeding in the exposed population.

Work has already been done in these areas and some is being extended. For example, the World Health Organization has a special committee at work on the problem of investigating human populations exposed to higher than average levels of ionizing radiation.

Studies of these kinds, taken together with conventional genetic assumptions and existing information from experimental studies, will permit improved assessments of the genetic risk for different radiation exposures. These, of course, may have to be revised periodically as more knowledge becomes available.

Investigations of the second type of project, necessarily more long-range in nature and aimed at extension of fundamental knowledge and at possible factors mitigating against radiation damage, are discussed with some overlapping under three headings: (1) mutation, (2) phenotypic effects of mutant genes, and (3) the behavior of genes in populations.

1. Mutation

We need to know the rates of spontaneous occurrence of mutation in specified categories and how these are influenced by radiation. To a considerable degree, information concerning these rates—especially the induced ones—will have to be deduced from what is known of organisms other than man. Such a process of extrapolation is not wholly satisfactory; the errors in so doing will be minimized if we have at least one mammal for comparison. We feel that experiments now under way with mice to determine mutation rates for specific loci as well as over-all rates for certain categories of mutations should be continued and expanded as rapidly as is feasible. The results will, however, give us more confidence if they are complemented with comparative data from a wide variety of organisms, including other mammals, since there is already evidence that different species may differ widely in spontaneous mutation frequencies and that individuals within one species likewise differ. The genetic control of such differences in mutation rate is itself in need of further study.

Most of the questions concerning radiation-induced mutations also need to be answered for mutations induced by other agents—abnormally high temperatures, ultra-violet light, various chemicals, etc. Although it seems reasonable to suppose that the germ cells of man are well protected from extraneous chemical substances to which large numbers of persons are exposed through ingestion, inhalation, or otherwise, it is nevertheless conceivable that some such substances as industrial and automobile fumes, foods and food additives, tobacco, drugs, antibiotics, hormones, cosmetics, contraceptives, and agents of chemical warfare may be important as possible sources of genetic damage to man. Chemical mutagens and antimutagens come within the special interests assigned to this Committee, since what is learned from their study may contribute materially to knowledge of the basic mutation process and the effects of ionizing radiations. This is especially emphasized by recent studies indicating that radiation-induced mutations may arise indirectly by way of intermediate chemical modifications of the cellular environment. It is also important to determine whether all these various agents produce similar spectra of mutations and especially the extent to which radiation-induced mutations are like "spontaneous" ones in the severity of their effects on the organism.

The degree to which mammalian germ cells *in vivo* may be protected from chemicals known to be mutagenic to microorganisms, to mammalian cells in culture, or to invertebrates in which the cells can be directly exposed, should be investigated in an experimental mammal such as the mouse.

Whatever organisms are used, the direct studies on mutation will need to take into account and elucidate the effect of such factors as age, sex, and physiological condition of the treated organism; cell type, stage of mitotic or meiotic cycle and the condition of the chromosomes; the exact type of mutant effect scored, especially how many different genes are concerned, and how sensitive the selected index is; the degree to which the technique is objective and free from personal bias; and the extent to which strain differences affect the results through the action of mutator or antimutator genes, or otherwise.

There are several different methods of study that lead to estimates of mutation rates for single loci, for all loci having a particular effect (e.g., lethals), for loci lying in a particular chromosome or chromosome region, or for the total effect per treated gamete. All are useful.

If it can be satisfactorily determined directly, the whole-gamete effect is the measure most immediately applicable for our purposes. The rates for specific loci are useful in indicating absolute rates for both spontaneous and induced mutations. But their greatest value appears to be in direct comparisons of mutation rates; for example, in comparisons of acute and chronic radiation. Since there is evidence that different loci vary in their frequency of both spontaneous and induced mutations, and not always in parallel, it is important to learn more about the extent and nature of such inter-locus variability. It is important not only to investigate point mutations at special loci but also structural changes of chromosomes of various types in relation to cell type, stage of life cycle, and nature of radiation or other mutagenic agent.

There are clear indications that in the spermatogonia and oocytes of mice, chronic irradiation is less effective in producing mutations than is the same total dose of acute radiation. This difference does not appear to hold for mature spermatozoa. However, it should be remembered that spermatogonia and oocytes are the cells that are most important in human genetic hazards. Clearly it is important to learn more about such phenomena, for they obviously bear directly on the problem of estimating the genetic hazards to man that result from increased radiation exposure. Differences in effectiveness of chronic and acute radiation make it important to re-examine the question of exact relation between induced mutation values and radiation exposure.

Although available evidence indicates that at relatively low radiation levels there is little selective survival of unaffected mouse spermatogonial cells as compared with those carrying mutations, differential multiplication of somatic cells may occur at radiation levels high enough to produce appreciable numbers of gross chromosomal aberrations. Additional and more refined measurements are clearly needed before it can be said under precisely what conditions such selection occurs, and, when it does, what its genetic significance will be.

More information is needed about the relationship between the mutation rates, spontaneous and induced, and the length of the life cycle.

What kinds of organisms should be studied? For a long time to come, many of the investigations can be carried out most effectively on experimental organisms such as bacteria, molds, Drosophila, and mice. However, there are important points at which human statistical data must provide key evidence, as for instance on the mutation rates of given genes and the behavior of mutant genes in human population genetics.

Additional work is also needed on the investigation of antimutagenic agents. There are already clear indications that such agents do exist and that they can be effective either before, during, or after exposure to radiation. We need to know much more about the action of these substances. For example, do they influence nonradiation-induced mutation? Since such agents are obviously of both theoretical and practical significance, it is important that their further study be expedited.

One of the difficulties in the study of the genetics of man is the small number of individuals available in any given pedigree. One possible way of avoiding this difficulty is through the study of somatic mutations, where one can hope to deal with large populations of cells. Here may be included studies on cell systems in the body (such as blood cells), cell cultures, tissue cultures, and tumors. Human, other primate, and other mammalian tissue and organ cultures are especially valuable in this connection. It has already been demonstrated that chromosome breakage in varieties of human cells growing and dividing in tissue culture can be related quantitatively to dosage. What we now need is comparative rates of radiation damage for many types of cells, and at different stages of the division cycle. Comparative rates of chromosome damage *in vitro* should be compared with those of cells *in vivo*. Interspecific comparisons, especially between man and mouse, will provide a better basis for extrapolating the genetic knowledge of mutation rates obtained in mouse studies to the human species. Comparative studies on identical or homologous tissues from males and females should be made in order to determine whether sex differences in response to dosage exist in human beings as they appear to in other species. If means of studying the mutation rates of specific human loci in suitable tissue culture cells can be worked out, it may be possible to apply methods of microbial genetics to the analysis of mutation rates in human tissue cells. Finally, if the successful methods of culture of human testicular and ovarian tissues already achieved can be utilized for the study of radiation damage to the genetic material, it is possible that a direct application of the knowledge derived from somatic and interspecific studies can be made to the problem of mutation in the human germ cells, at least in the oogonial and spermatogonial stages.

. It is possible, and thought to be likely by many geneticists, that some malignant neoplasms may owe their origin to somatic mutations. For this reason we feel that the application of genetic methods to the study of malignant neoplasms is one of the important aspects of the study of mutagenic effects of radiation.

In this connection particularly, we emphasize that present knowledge is all too limited as to the effects of low levels of radiation in inducing malignant neoplasms. We cannot say with any assurance whether the dose-response curve for induction of malignant diseases is linear or non-linear at low levels. Regardless of whether some or all such diseases arise through somatic mutation, it is urgent that more information be obtained on this point, for it is just at these low levels of exposure that the practical questions of human hazards have now become important. We believe that studies of this kind on experimental mammals should be extended and expanded, even though they are difficult. These must be done on a large scale and should include effects of accumulated internal emitters of several kinds, especially the radiostrontium isotopes. Perhaps mice and rats are the most suitable organisms for this purpose because of their small size and the availability of many relatively homozygous lines. In the latter connection, it is suggested that lines with low incidences of malignant disease be included; for in lines in which the control incidences are high, small increases due to low levels of added radiation will be especially difficult to detect. In attempts to argue from experimental animals to man with respect to radiation-induced malignant neoplasms, it may well be important also to investigate experimental mammals with life cycles much longer than those of the otherwise favored small rodents.

In all respects—incidence of malignant changes, incidence of traits known to be genetically differentiated, as well as developmental abnormalities that are less clear genetically—it would seem that emphasis should be given to investigations of human populations known to be or to have been in previous generations exposed to radiations at levels that can be estimated. These should include such studies as are now being made on survivors of A-bomb exposure at Hiroshima and Nagasaki, populations living or working in areas of much higher than average background level, industrial workers exposed to radiation, radiologists, X-ray technicians, and persons given medical radiation for diagnosis or therapy. Obviously such investigations must extend over more than one generation. Difficult and unsatisfactory as this approach is—and is likely to remain, it should be pursued with great vigor, for it is to be hoped that human material so exposed in the future will be less prevalent than it now is. There should therefore be no delay.

In addition to making effective use of all currently available methods and techniques for the study of human genetics, investigators should be given constant encouragement in searching for new approaches. It is conceivable, for example, that entirely new methods of directly investigating human chromosomes can be found. It would be of great value to have biological means of estimating accumulated radiation exposure in man. This might be possible by some method of quantitatively determining accumulated chromosome breaks. Improved methods of measuring physiological age would be most useful in investigating the relation of induced mutations, including chromosomal breaks and rearrangements, to the aging process.

2. Phenotypic Effects

It is obvious that mutations are of importance to human populations because they lead to significant variations in developing individuals. The extent of damage due to unfavorable mutant genes will depend on two factors: their frequency in the population and the harm they do to individuals.

In both respects, there are serious difficulties in making estimates. In the latter regard, it is misleading in some connections to attempt it in numerical terms. How, for example, does one measure quantitatively the relative importance of a still-birth, a feeble-minded child, and a death during adolescence? One may rate such things in the order of their significance either for society or for the families of the affected individuals, but clearly no simple numerical formulation can describe the relative human values. (The following contribution by Sewall Wright presents one suggestion as to how problems of this kind might be approached.)

While an over-all figure must in this sense be inadequate, it is still possible and desirable to get estimates on the relative frequencies of different types of mutant abnormalities, as expressed in rather broad categories (e.g., early or late embryonic deaths, infant deaths, mental defects, sterility, etc.). Much genetic damage is of course not observed by the usual direct methods. As pointed out in the United Nations report referred to earlier, it is probable that the magnitude of this fraction of undetected genetic damage in man can be estimated through careful comparison of the children of cousin marriages with those of parents less closely related. Until reliable data of these kinds become available for man, estimates will have to be based in part on information from other organisms.

There are certain general properties of mutant genes that are in need of more study. Our 1956 report emphasized that many radiation-induced mutants would exert their chief effects through small dominant effects. This question of the degree of dominance, and its variation among loci, needs additional study because, among other reasons, of its bearing on the number of generations in which mutations will persist in populations.

Although the magnitudes of the selective disadvantages of heterozygotes for mutant genes usually called recessive may be small and therefore difficult to detect, they may nevertheless be of such overriding importance in the elimination of deleterious genes as to deserve especially thorough investigation. And for the same reasons it is essential to know the frequency and importance of loci for which there are selective advantages of heterozygotes—that is, "over-dominance." Several instances are now known in man in which it has become very likely that there are such selective advantages of heterozygotes for deleterious mutants over their "normal" homozygous counterparts. Incomplete dominance and overdominance should be studied for mutant genes produced in a variety of ways—by "natural" mutation, by artificially applied radiation, and by treatment with other mutagenic agents.

Some mutant genes produce large effects that are easily identified; many more produce smaller effects that are often difficult to analyze. We need more information on the frequency and properties of this latter type. It may be hoped that new methods of study applicable to man will be developed; but it is also desirable that the rather laborious (and sometimes discouragingly inconclusive) methods now available be further exploited, and that all methods be applied as widely and as rapidly as possible.

Mutant genes also differ in the type of character involved, and the techniques necessary for their study are correspondingly varied. Some of the types of characters that are important from a social point of view are especially difficult to analyze—those having to do with mental properties, for example. It is important that twin studies be pursued here, and that other methods of approach be developed. Perhaps additional progress could be made by the study of behavior patterns in laboratory mammals; these might at least give some indication of the relative frequency of mutations in some components of the mental makeup of individuals.

Estimates of damage due to mutation will be affected by the frequency of "pleiotropy" (multiple phenotypic effects of single genes), of "synergism" (greater than additive cooperation of genes at different loci in producing a given effect), and of cases in which given mutant effects are simulated by mutations at other loci or by environmental effects. We need evidence—especially from man and other mammals—on the relative frequencies of interrelations of these and similar kinds among genes (especially radiation-induced mutant genes) and among characters.

Almost any mutant gene varies in its effects on different individuals that bear it; at times this variability may be extreme, ranging from no detectable effect at all up to extreme malformations. Such variations are sometimes due to detectable genetic or environmental causes; in other cases, they have the appearance of occurring at random. The frequency and characteristics of the phenomenon need study—again especially in mammals—since they will be important in any attempt to make quantitative estimates.

3. The Behavior of Genes in Populations

If we knew the quantitative relations between mutation frequency and radiation dosage, and also had good estimates of the amount of damage to an individual resulting from each mutant gene produced, we still would not have solved one of the problems presented to us, namely, what happens to these genes when they are introduced into the population, and also what happens to the population.

This type of problem requires a knowledge, not now available, of the breeding structure of human populations. We need to know such things as the degree of inbreeding (frequency of marriages between first cousins and more remote relatives) and its relation, as well as that of other factors, to number of descendants. Some of the needed kinds of information can be extracted from existing vital statistics and hospital and other medical records; it is to be hoped that methods of collecting and filing such statistics can be instituted that would make them much more useful for this purpose. In this connection it may be pointed out that one of the unique features of man as a genetic organism is that pedigrees are recorded in one way or another for many generations and for many hundreds of millions of individuals. Human geneticists have only begun to exploit this special advantage.

We are poorly informed of the way in which natural selection is now operating on human populations. Only after a very detailed study of mortality and fertility rates and the factors influencing them will we be in a position to give reasonably clear answers here—and only then will we be able to make reasonably sound estimates as to the future fate of mutant genes and their effects on the population bearing them.

Human population studies should include vital statistics on genetic abnormalities and diseases as well as the results of metrical, physical, physiological, mental, and behavioral tests. Particularly important may be detailed vital statistics, as related to the level of consanguinity, in populations now or recently living under primitive conditions more nearly similar to those under which present gene frequencies may have been determined.

One may question whether it is possible to establish artificial populations of experimental animals that will approximate the reproductive potential and the breeding structure of human populations. Nevertheless it is important to learn as much as possible about the behavior of such populations under varying conditions, including exposure to different levels of radiation.

There are some considerations in human populations studies that are not important in connection with populations of other organisms. It is not easy to see how they can be studied directly, but they seem worth pointing out. One such consideration is that human society depends on diversity of performance among its members, and on very high mental qualities among at least some of them. In the absence of any precise information on the extent to which mental qualities are inherited, it is not now possible to evaluate the genetic component in this requirement. But the fact remains that it is possible that a human civilization might conceivably collapse simply from becoming qualitatively inadequate, even if reproductive selection of certain kinds were operating with high intensity and the number of individuals in it remained at a level that was previously optimal.

Another consideration is that natural selection is an impersonal process that often involves suffering. On ethical grounds, many geneticists would like to see methods that involve less human suffering come into more general use for the control of the genetic constitution of human populations. This seems at present a Utopian idea, but it remains one that many biologists hold to be desirable. If significant advances in this direction should be made in the future, they will necessarily have a bearing on the genetic hazards of increased exposure of man to high-energy radiation.

4. Basic Research

The Committee feels that it cannot too strongly urge that the pace of basic research in genetics be increased, for answers to many of the practical questions posed above will surely come in this way.

Encouraging progress has been made in recent years in understanding the physical and chemical nature of genetic material and every effort should be made to extend this understanding as rapidly and as far as possible. We need to know more about the nature and organization of genetic specifications, how they are replicated, the manner in which they are changed through both spontaneous and induced mutation, and the way they are used in development and in physiological activities.

Because the production of specific antigens and antibodies is important in both theoretical genetics and in many practical problems involving radiation damage, immunogenetics is a field that should receive strong support in any long-term research program in basic genetics. Especially in the genetic investigations of populations of cells in multicellular organisms, immunogenetic methods are of significance. In the case of massive radiation damage in mammals, the promise of bone marrow replacement therapy has already more than justified this view.

There is urgent need for deeper understanding of the primary effects of high-energy radiation on living systems. New methods and tools for attaining this end are being rapidly developed. The use of chemicals in preventing damage should be further studied so that a better understanding can be reached of the metabolic steps between absorption or radiation and mutation. Emphasis should be given to application of physical methods now available for analyzing reaction pathways in mutagenic processes.

In all such studies the experimental material used should obviously be that most appropriate to the problem being investigated. Nucleic acid or protein, in the test tube or analytical ultracentrifuge, may be the system of choice. Viruses promise to become even more important than they now are as tools of geneticists. The interactions of viruses and their host cells will surely be of increasing importance in the search for new genetic knowledge. Bacteria, fungi, algae, protozoa, as well as higher forms of plants and animals, will of course continue to make their contributions. And whenever and wherever such basic investigations can be made with human materials, including tissue cultures, these should by all means be used.

IV. How To Expedite Needed Research

Many of the investigations needed for the desired refinements of estimates of the genetic hazards to man of given levels of radiation are now under way in various academic institutions and in special research laboratories supported privately and by governments. No doubt appropriate additional financial and other encouragement would be effective in speeding up these efforts and in otherwise making them more effective without requiring unrealistically large additions to present manpower at the higher level of scientific competence.

Government agencies such as the Atomic Energy Commission, the Public Health Service, and the National Science Foundation, as well as international agencies such as the World Health Organization and United Nations committees, are constantly reviewing their over-all research programs. It is especially important that this be done in the area of radiation hazards, for the various large-scale uses of radiation for peacetime and military purposes are developing at a rapid rate.

In the specific area of genetic hazards—the special province of this committee—both government and non-government laboratories and agencies in the United States and other nations should see to it that needed research is done well and as rapidly as feasible. No doubt in certain areas the research effort needs strengthening. In others in which there is now no activity, it may need encouragement.

How best to do this is a question on which both investigators and administrators have wide differences of opinion. Some would say that all that is necessary is to see that able investigators are adequately supported—that they will find the gaps in our present knowledge and devise ways of closing them. Others would say that coordinating committees are needed to make systematic surveys of what needs to be done and recommendations as to how to get it done.

Perhaps no one approach can provide a complete solution. No doubt both government and private agencies will continue to use staffs of professionally trained geneticists and to appoint advisory committees and study panels to assist them. The Federal Council of Science and Technology may well choose to sponsor a review of the present total effort in the radiation hazards field.

Whatever the approach, it is most important that able investigators with creative ideas be identified, be given adequate facilities, be provided stimulating environments for their work, and be given reasonable assurance of continued support. If this is done well, many of the problems that would otherwise go unsolved will be taken care of with competence and dispatch.

1. Genetics in Medical Schools

Entirely aside from the problem of more accurately estimating radiation hazards to the hereditary material of man, there is an important need for an increased emphasis on genetics in the training of medical personnel. It has been estimated that something like two per cent of the population are born with significant genetic defects now demonstrable. When one considers that for the population of the United States alone this may mean as many as 80,000 individuals born with such genetic defects each year (of which perhaps 4000 are homozygous for an assumed single gene differentiating the incurable and often fatal disease cystic fibrosis of the pancreas), one gains some proper appreciation of the magnitude of the medical problem of heritable diseases in man. Not only is it important that members of the medical profession be better acquainted with present knowledge of the nature of such diseases and know what can or cannot now be done to alleviate or cure them, but in the long run it is even more important that they do more to help advance knowledge concerning their genetic bases. Millions of persons receive some medical attention every year in the United States, and members of the medical profession are therefore in a most favorable position to discover what medically significant traits are inherited and how. Obviously they cannot do this unless they have a better understanding of genetics than they now receive in most medical schools.

There has recently been an encouraging trend toward the appointment of geneticists by medical schools and there are now perhaps a dozen such schools with first-rate and well-trained modern geneticists on their faculties. The number should be increased as rapidly as manpower will permit. In many instances the limiting factor is financial rather than any lack of adequately trained and interested manpower; a relatively few millions of dollars invested in additional permanent faculty positions in medical genetics in the United States would go a long way toward improving the situation.

The above arguments imply the desirability of revision in medical school curricula to include, or require for entrance, a sound training in modern genetics.

2. The Utilization of Medical Records

Medical records, as normally kept by individual practitioners and by hospitals, are not designed to be maximally useful in determining the genetic basis of various diseases. It seems clear that they could be improved enormously in this respect at relatively little cost.

For example, if they were designed in such a way as to permit simple machine association of family name and specific disease, they could be used in providing clues as to what conditions might be looked into with profit from a genetic point of view.

It is recommended that the possibility and feasibility be explored of designing a model form of medical record that would take into account its use in genetic surveys. How this might be done is considered in the following closely related section on census data.

3. Census Data and Human Genetics

As with medical records, census records as now taken in the United States are of relatively little use in genetic investigations, for they were not planned with this use in mind. A thorough study of the feasibility of revising present census practices in the United States and other countries with a view to increasing their usefulness to human genetics seems clearly indicated. It is evident that the problem of how best to do this, even in a single nation, is a large and complex one. The obvious advantages are so many, however, that this Committee urges that an effort be made as soon as possible to look into the matter in the United States.

Since this question of census records is so closely related to that of medical records in general, serious consideration should be given to the commissioning of a special study group to consider the two problems together. To be effective, such a study group should include representatives of the medical profession, of the Bureau of the Census, of geneticists, and of statisticians. Full advantage should be taken of the Canadian experience, preferably by inviting participation by members of the group responsible there. Such a study will undoubtedly be a difficult and time-consuming one. The group selected to make it should consist of persons not only properly qualified but also prepared to give adequate time and attention to it.

4. The Support of Basic Genetic Research

The uninhibited search for new knowledge for its own sake, without regard for its immediate or even potential usefulness, has provided the main foundations for modern genetics as it has for all other branches of science. It is therefore of the utmost importance that such free inquiry in genetics should not decline in quantity or quality at the expense of investigations designed to solve problems of immediate practical value. It would be most unfortunate if, because of superior facilities, higher salaries, or otherwise, manpower should be drained away from basic genetic research to any significant degree. If the practical jobs that need doing are to be done without decreasing the relative effort in basic work, new ways must be found for supporting imaginative and creative workers in genetics and related fields and in providing environments most conducive to their best efforts.

Although they do not always succeed in doing so, academic institutions have long had as one of their primary objectives the providing of environments favorable to creative achievements in all branches of knowledge. In the last several decades, however, they have probably declined relatively in this regard, especially in the sciences. During this period funds for research in science have increased manyfold while the faculty members with tenure in academic institutions, even those in science, have increased by a relatively small factor. The resulting imbalance is in need of correction in genetics as well as in other areas of science if the search for new knowledge is not to become a serious limiting factor in overall progress.

5. The Manpower Problem

If rapid progress is to be made toward the solution of the practical problems referred to earlier in this report, and if, at the same time, efforts in basic research are to be increased, the question immediately arises as to where the necessary manpower is to be found.

There are two obvious possibilities: (1) more effective use of present personnel through the provision of better facilities and probably additional technical help, and (2) the training of more research workers in genetics. The first will depend on adequate financial support plus wise administration at all levels. The second will come about if the teaching of genetics is sufficiently inspired and enlightened, and if careers in genetics are made attractive enough in opportunity, stability, and financial reward.

With recent substantial increases in funds for research in genetics, along with corresponding increases in other areas of science, such activity in academic institutions has been increased largely through the employment of postdoctoral research fellows or research associates on a temporary basis wth funds granted for short terms and for specific projects. The result has been a relatively large increase in non-tenure staff members who do little teaching and for whom the prospects of obtaining regular teaching or research posts are discouragingly small. The creation of additional faculty-level posts in genetics would appear to be a solution. This will require that suitable long-term sources of financial support be found for the purpose.

6. Continuity of Support

Many of the needed studies in genetics, especially those involving experimental mammals and men, require continuous effort over many years. Without some reasonable assurance of continued support, financial and other, there is an understandable reluctance to initiate such investigations. Investigators of high competence cannot be expected to associate themselves with long-term projects unless they can reasonably look forward to continuing support at realistic financial levels. It is therefore of the greatest importance that ways be found for reducing the present uncertainty in these respects. Both capital grants for specific areas of study and long-term program grants, the latter regularly renewed well ahead of expiration dates, should go a long way toward improving the present situation. There are in fact encouraging signs that some governmental and other fund-granting agencies are coming to recognize this need and are making real progress in meeting it.

George W. Beadle, *Chairman*
H. Bentley Glass, *Rapporteur*
James F. Crow
M. Demerec
Theodosius Dobzhansky
G. Failla
Alexander Hollaender
Berwind P. Kaufmann
H. J. Muller
James V. Neel
W. L. Russell
A. H. Sturtevant
Shields Warren
Sewall Wright

On the Appraisal of Genetic Effects of Radiation in Man

By Sewall Wright

Any attempt at appraisal of genetic damage to man from ionizing radiations must begin with the problems of defining what is meant by genetic damage in the human case and of measuring it. Only when these are answered can there be any concrete estimate of the current genetic burden. Finally there must be an estimate of the amount of increase in radiation required to double the mutation rate in man before the impact of a given increase in exposure to radiation for one generation or for a succession of generations on the immediate and ultimate genetic burden can be appraised.

There is no question that all that can be learned about mutation and the effect of mutation in lower forms is pertinent. Without the evidence already obtained from such research on the relation of dosage to mutation rate in organisms in general, there would be no possibility of an early appraisal of the effects in man. It is to be hoped that further fundamental research will strengthen our knowledge of this relation and perhaps also lead to ways of mitigating the effects. This presentation will, however, be restricted to needed research in man.

Some of the researches needed are unfortunately in the unpopular and scientifically somewhat unrewarding borderline fields of genetics and the social sciences. Progress in this aspect of the general problem is likely to be slower than that in the scientifically more attractive fields that have a less direct bearing on it.

There is one point of view under which the appraisal of genetic damage from increased radiation is a relatively simple matter. If we assume that there is one best genotype and that this is homozygous in all type genes, it follows that all mutational changes from this are injurious and selected against. For each mutation there will be on the average one elimination (or "genetic death") to restore the status quo (in a static population; more than one in a growing population). If we define damage in terms of number of genetic deaths, it follows that all mutations produce equal damage in the long run and it merely becomes necessary to estimate the number of mutations produced by a given amount of radiation to appraise the damage.

There are, however, several considerations that make this point of view unsatisfactory.

In the first place, the concept of a single type genotype probably does not apply to any organism and particularly not to human populations in which extreme diversity is itself essential to a healthy state of society. It is probable that the optimal state of any population is one in which many alleles with slight differential effect are carried at a large proportion of all loci at more or less equal frequencies. Even conspicuously unfavorable effects of mutations in particular combinations may be balanced by favorable effects in others.

In the next place, the equating of all unequivocally injurious mutations is very unrealistic without consideration of the personal and social impact. It will perhaps suffice here to note that the occurrence of a dominant mutation, lethal in the first week of development, will produce no appreciable damage to the population or to any one in it. There will be no appreciable damage to society and little to any person from a mutation that causes a slight reduction in fecundity of otherwise wholly normal carriers in a population that is in balance with its natural resources, and there may be some advantage to a society that is suffering from overpopulation. On the other hand, a dominant mutation that gives rise to a distressing and incapacitating but not lethal condition that is usually not manifest until after the family is complete may produce enormous personal and social damage before becoming extinct. It is indeed conceivable that there is a class of mutations that endows its carriers with capacities for parasitizing society that cause them to increase in numbers until society collapses.

Even in lower organisms it is necessary to distinguish between intrademic selection that may in some cases lead to the increase of certain mutations at the expense of the welfare of the population, and interdemic selection that may in some cases lead to the establishment of mutations that are individually at a slight disadvantage but that make for the success of the group.

As a first step in the problem of appraising genetic damage, it is desirable to attempt some classification of human phenotypes with respect to social value. This is primarily a sociological problem but collaboration is needed between a sociologist familiar with the data and its sociological appraisal, and a geneticist who can aid in the choice of the classification most useful in the light of genetic knowledge. The following rough classification does not meet these specifications but may suffice to indicate the nature of the problem and give a provisional basis for discussion of the genetic problems.

The social impact of a mutation may be treated in terms of the balance between contribution to society and social cost. In general, there is a positive correlation between contribution and cost. Those who contribute most also tend to cost the most in terms, for example, of education and standard of living. An injurious mutation may, however, entail a heavy diversion of the efforts of others into a channel that is unproductive to society except from the standpoint of maintaining the sacredness of human life. In dealing with contributions, such efforts must be included even though in a sense wasted, as of course must efforts in rearing one's own or other children. The contribution from fecundity itself, however, is ambiguous. It must be considered separately in connection with genetic considerations.

It should be added that there is a personal aspect of genetic damage that may not be reflected to any appreciable extent in social impact. There are many conditions that are personally undesirable but that can be tolerated or remedied so easily that there is little or no effect on the balance of social contribution and cost. The appraisal of genetic damage from this personal standpoint is much more intangible than the impact on society. For the moment we will consider only the latter.

The various combinations of cost and contribution to society that exist in a human population are shown schematically in the diagram on page 20.

The diagonal dotted line is that in which the ratio of contribution to cost is average for the population in question. This ratio may be taken as one in a static society but as greater than one in a society in which there is an advance in well-being in each generation.

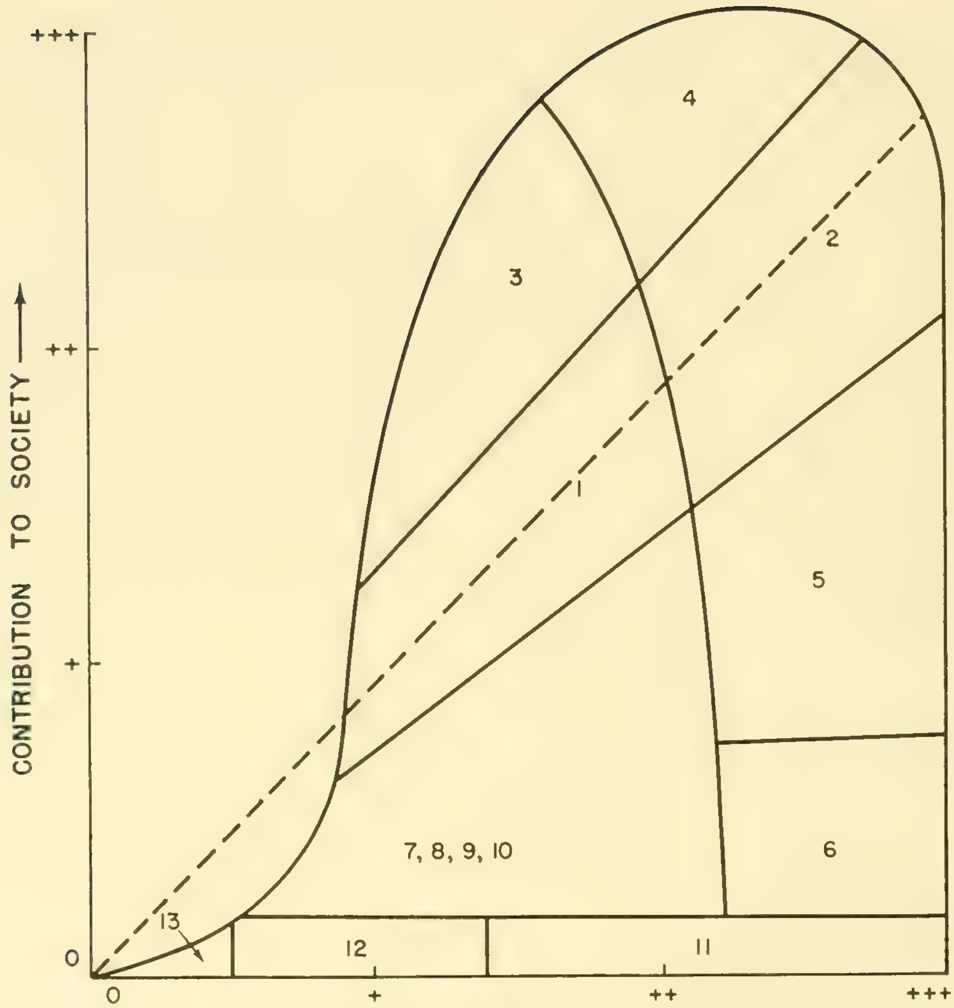
1. In the first category, which includes the bulk of the population, there is an approximate balance between contribution and cost, but both at relatively modest levels.

2. In this category, there is also an approximate balance between contribution and cost but both at relatively high levels. Professional men of average competence, but with an education and standard of living well above the average of the population in cost, fall here.

3. Here are included those who make an extraordinary contribution at modest cost to society.

4. In this category are those who cost society much in terms of education and standard of living but who contribute much more than the average at their level of cost.

5. We may put here a class of individuals whose capacities are those of classes 1 to 4



COST TO SOCIETY

PHENOTYPIC CLASSES:

1. Contribution = cost at low level
2. Contribution = cost at high level

3. Contribution > cost at low level
4. Contribution > cost at high level

5. Contribution < cost because of unearned wealth, etc. (playboy type)
6. Contribution < cost because of antisocial career

7. Contribution < cost because of subnormal physical constitution
8. Contribution < cost because of subnormal mentality
9. Contribution < cost because of interruption of career by physical breakdown
10. Contribution < cost because of interruption of career by mental breakdown

11. No contribution, high cost because of complete incapacity from childhood (long life)
12. No contribution, moderate cost because of death before maturity
13. No contribution, little cost because of pre- or perinatal death

but whose return to society is definitely less than their cost for such reasons as unearned wealth.

6. We may put here individuals of normal physical and mental capacity whose cost to society definitely outweighs their contribution because of the antisocial character of their efforts: charlatans, political demagogs, criminals, etc.

In the remaining categories cost to society definitely outweighs contribution because of physical or mental defects.

7. Subnormal physical constitution and health.

8. Low mentality but not complete helplessness.

9. Normal to maturity but relatively early physical breakdown, either from accident, infectious disease, or relatively early onset of degenerative disease. The seriousness of the deviation from a normal balance of contribution and cost varies with the earliness of onset and the duration of the period of disability.

10. Mental breakdown after maturity, especially from one of the major psychoses.

11. Complete physical or mental incapacity throughout a lifetime of more or less normal length.

12. Death before maturity and too early for any appreciable contribution to society.

13. Death at or before birth.

Categories 1 to 4, in which contribution balances or outbalances cost, include an enormous diversity of type. It is not necessary for our purpose to attempt to characterize them further.

Category 5 is almost wholly nongenetic and needs no consideration here.

Category 6 which is probably the most damaging to society is unfortunately highly controversial with respect to the roles of heredity and environment and must be considered further.

The remaining categories (in all of which cost to society outweighs contribution) all undoubtedly include a significant genetic component. They overlap broadly in location on the cost-contribution diagram. Each could be subdivided according to levels of cost and contribution but this is unnecessary for our purpose.

Fecundity is not included in the concept of contribution because of its ambiguous sign. In general high fecundity may be considered as making a positive contribution in categories above the line of balance and a negative one below, not only for possible genetic reasons but also for directly social ones. The line between positive and negative contribution may be considered to shift up or down somewhat according to whether there is over or under population. Fecundity seems to be actually highest in category 1 and to fall off in all directions. It is practically zero along the bottom line.

The diagram does not bring out the value of diversity. Particular types in the broad categories (1 to 4) along or above the neutral line tend to have value inversely to their frequencies. There may be too many or too few in a subclass with particular qualifications for a well-balanced society.

We come now to the enormously more difficult problem of genetic appraisal. The best first step seems to be a classification of the processes by which each sort of mutation is maintained in the population.

A. Mechanism of equilibrium primarily that of opposed selection pressures.

1. Positive selection coefficient below a certain frequency, negative above.
2. Heterozygote favored over both homozygotes.

B. Mechanism of equilibrium primarily that of opposition between pressure of recurrent mutation and adverse selection.

1. Adverse effect in heterozygote.
2. Adverse effect in homozygote. Complete recessive.

Alleles of the A class have an effect on variability far out of proportion to the frequency of occurrence of mutations since they tend to be held at high frequency. Thus if we take $s = 0.04$ as the average selective disadvantage of type B heterozygotes and $v = 4 \times 10^{-6}$ as the average mutation rate, the mean gene frequency at equilibrium is $v/s = 0.0001$. If type A mutation can also occur at these loci but with an average rate of only 4×10^{-10}, 99.99% of the mutations that occur are of type B. Nevertheless if the type A mutations reach equilibrium with a mean gene frequency of 0.10 because of the postulated opposed selection pressures, there will be one thousand of them for each deleterious B gene in the population and they could be responsible for most apparent genetic defects. Changes in dosage of ionizing radiation have no appreciable effect on the incidence of this sort of gene defect. It is the price the population must pay for the advantages of these same genes in other individuals.

In the case of deleterious mutations of class B, on the other hand, an indefinitely continued excess dosage of radiation tends to bring about ultimately a corresponding percentage increase in the frequency at which the effects of all such mutant genes are manifested in the population. The mode of approach to equilibrium is very different for mutations with heterozygous deleterious effect and for those that are completely recessive. In the former, the deviation from the new equilibrium tends to be $(1-s)^n$ of its initial value in n generations, where s is the selective disadvantage. Thus in the case of a dominant lethal with complete penetrance, the full effect occurs in the first generation (and full recovery occurs in the first generation after cessation of the excess radiation). With $s = 0.10$, it takes about 7 generations to go half way to the new equilibrium, and with $s = 0.01$, about 69 generations for this to happen. Recovery after cessation occurs in the same way. In the case of a completely recessive mutation, the approach to the new equilibrium is excessively slow ($2\sqrt{us}$ of the ultimate effect per generation at first, where u is the mutation rate and s is the selective disadvantage). Thus a recessive lethal ($s = 1$) arising at the rate 10^{-5} per generation goes only 0.6% toward the new equilibrium in each early generation. The recovery rate is a little more rapid at first but still exceedingly slow. With respect to the next thousand years, the mutations due to excess radiation that will cause appreciable damage are those of class B with selective disadvantage of the heterozygote greater than 0.01.

We need not pause long on mutations that merely cause differences within categories 1 to 4, as far as damage to society is concerned. There are no doubt many types of mutation that are undesirable from the personal standpoint but these are likely to be held at low frequencies by adverse marriage selection.

The extreme diversity of physical and mental types that can find a satisfactory niche in modern civilization provides an enormous amount of buffering against defects that would have been damaging in primitive man. Conditions that incapacitate for some ways of making a living may make no difference in others. Some conditions that would have been highly damaging once can be corrected at little cost in modern civilization (e.g., visual defects that can be corrected by glasses). Medical advance is continually reducing the amount of damage from many conditions. This does not mean that natural selection is ceasing to operate. It is merely being redirected into the channels most significant today.

Nevertheless the increase in gene frequency, in defects that are undesirable merely from a personal standpoint, due to mutations of class B, must certainly be given weight in appraising the effects of increase in ionizing radiations. There is already much evidence on rare family traits that probably belongs here.

As far as burden to society is concerned, class 6, antisocial behavior, probably comes first. *A priori* one might suppose that selection would have been redirected especially into the channel of social adaptability since the advent of civilization made certain types of behavior, that had been highly adaptive in primitive life, highly disadvantageous to society. This, however, is on the assumption that heredity is involved to a sufficient extent to give a handle to such temperamental traits as egotism, aggressiveness, impulsiveness, and their opposites, but disentanglement from the effect of social training makes appraisal extraordinarily difficult. The effect of increased radiation in increasing character defects that lead to antisocial behavior is not likely to be determined soon.

Category 7, socially burdensome subnormal physical constitution, brings us to the heart of the problem of appraisal. It is possible, on the one hand, that most defects of this sort are due to heterozygous effects of mutations of class B with the consequence that most of the social burden must be included in a genetic burden that is expected to rise with increased radiation. On the other hand, most of it may be either accidental or due to mutation of class A and thus not subject to appreciable increase with increased radiation. In the last case, the current burden is the price that society must pay for the diversity in categories 1 to 4 that is essential for modern civilization. The problems for investigation are thus those of the heritability of deviations in this category and the proportion of the heritable portion that is due to mutations of type B, especially B1.

The situation is the same with respect to category 8, the burden from subnormal intelligence. A considerable portion is certainly non-genetic (effects of birth injury, early infection, etc.). Another portion is probably the price that must be paid for a distribution of intelligence with a peak best adapted for performance, without too much boredom, of the great bulk of the work needed in the present imperfect state of society, but an upper tail of sufficiently high intelligence to furnish necessary leadership. Under multifactorial heredity this implies a somewhat corresponding tail of low intelligence. Some of the burden is undoubtedly due to mutations of class B. Again we have the problem of heritability and apportionment of the heritable portions to classes A and B for investigation.

The case of category 9 (burden from physical breakdown, after maturity but before the debt to society has been paid) is also similar. Here accidental causes probably play a greater role than in feeblemindedness but it is reasonably certain that genetic factors are of considerable importance in such matters as susceptibility to tuberculosis and other infectious diseases, diabetes, circulatory diseases, and cancer. The problems are the same as before.

In the case of mental breakdown (category 10), heredity undoubtedly plays a very important role. Huntington's chorea is due to a dominant gene with 100% penetrance for all who live long enough. It is definitely due to a mutation of class B1 and does very considerable social (and personal) damage.

The most important part of the burden in this category is, however, that due to the major psychoses, schizophrenia, and manic depressive reaction. Penrose, in the report of the British Medical Research Council, adopts Kallmann's interpretation of a recessive predisposition to schizophrenia. He assumes a 1% incidence of homozygous recessives in the population and that 10% of these are chronically incapacitated with a reduction in fecundity of 50% ($s=0.05$).

The mutation rate that would maintain a frequency of 1% homozygotes against a 5% selection disadvantage is 5×10^{-4}. This is on the assumption of a single locus. It would be reduced tenfold if there were 10 equivalent loci. Accepting provisionally the hypothesis of only one locus, the estimated mutation rate is so high as to suggest that the observed incidence is due to balance of opposed selection pressure (class A) rather than to adverse selection balanced by mutation (class B). If this is the case, the burden of overt schizophrenia is the price society pays for benefits conferred by persons of slightly schizoid type among the heterozygotes or the 90% homozygotes that do not break down. The effect of increased radiation would be very slow even if a gene of class B is responsible, if the condition is recessive. The predisposition to manic depressive reaction is treated by Penrose as due to a dominant gene with frequency of heterozygotes of about 0.5% in the population, 14% breakdown of these with loss of fecundity of 10% ($s = 1/70$). This leads to an estimated mutation rate of 0.000035. This is considerably lower than for schizophrenia but raises the same question.

It is thus far from certain what the effect of increased radiation would be in the burden from the major psychoses. It is among the most important problems in the field to obtain a better understanding of the genetic situation, for in neither case is it likely to be as simple as assumed in the above analysis.

With respect to categories 11 and 12 (burden from completely incapacitating conditions that appear at birth or in childhood leading to early death (12) or incapacity of long duration (11)), there is a considerable portion that is certainly nongenetic (birth injury, childhood infection, etc.) but also a well recognized portion due to rare genes, undoubtedly of types B1 or B2. The effect of increased radiation on the genetic burden can be estimated more reliably than in any of the other categories though there are still plenty of problems.

Embryonic and fetal death (category 13) is known to be due often to maternal virus infection and other nongenetic causes. There is no doubt also a genetic component but this is obviously more difficult to analyze than in categories 11 and 12. This is not of primary importance since the genetic burden is less important.

From this survey it may seem that a minimal estimate of the effects of increased radiation can be obtained for consideration of rare family traits in categories 11 and 12 and some (such as Huntington's chorea) in others. The total effect is probably considerably greater and may be enormously greater depending on appraisals of heritability and of the portion of that heritable in class B, especially B1 in such conditions as poor physical constitution, feeble mindedness, physical and mental breakdown in maturity.

Report of the

COMMITTEE ON PATHOLOGIC EFFECTS OF ATOMIC RADIATION

REPORT OF THE

COMMITTEE ON PATHOLOGIC EFFECTS

THE Committee on Pathologic Effects of Atomic Radiation and its Subcommittees, since the publication of their report of June, 1956, have been reviewing all available data pertinent to the field. The Committee is grateful to the United States Atomic Energy Commission, the Department of Defense, the United States Public Health Service and numerous investigators for providing pertinent data.

This report is essentially similar to our last Summary Report. Appendices will be published by several of the Subcommittees during the next few months bringing up to date the data in their appropriate fields of competence. In presenting this report, it has seemed best for completeness to republish much of the original report, with the additions and emendations to that report shown in italics. Some omissions have been made in the original report to improve brevity and clarity.

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, *as have some other species. Therefore, not all experimental data on animals are directly transferable to man.*

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 radiotherapy, 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 *thermal* burns or other injuries. The acute lethal dose *of whole body radiation* 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 almost any cost.

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 time period during which persons may be overexposed to radiation will have much influence on the overall effects. For example, total body irradiation in a relatively short period of time, as occurred in Japanese atomic bomb casualties and in a few accidental exposures in atomic energy plants, caused early clinical effects reflecting mainly injury to the blood-forming tissues and intestinal tract, which have great powers of recovery, as well as leukemia and other delayed effects in various organs.

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 as yet.

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." *There is some evidence in animals that radiation effects contributing to shortening of life span may depend upon genetic constitution and on the age and physical or clinical status at the time of exposure. In general, for given dose rates, the survival time is shorter the more radiation energy absorbed. Life shortening is generally less, however, for a given total dose absorbed over a long period of time as compared with a short period of time. Life shortening in man has not been demonstrated following small doses of radiation.*

Statistical studies of mortality of U. S. physicians, comparing radiologists with other physicians or with the general male population, indicate that occupational exposure of U. S. radiologists may have caused an increase in mortality in past decades. Since the increase is of borderline significance, it is not yet possible to make quantitative determination of life shortening. A study of British radiologists suggests no increase in mortality rates among them.

A life shortening effect in man as a consequence of substantial total body irradiation can be estimated reasonably on the basis of animal experimentation and on the basis that such exposures increase the incidence of leukemia in human populations. However, there are as yet no data for man that provide a satisfactory basis for quantitative estimation of the overall life shortening effect, the existence of a dose threshold, or of the dependence of the effect on dose and dose fractionation.

The lethal dose for partial body irradiation exceeds in general, that for the whole body. A small volume of tissue may receive many thousand roentgens without death resulting. This permits doses much greater than the lethal level for total body radiation to be employed in radiation therapy.

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 (leading to cancer as a late development) is a well-known example of this mode of exposure. It is worth noting that the atomic energy industry, through *careful preventive measures,* 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.

*Blood-Forming Tissues**: Among the more serious effects of radiation are those on the blood, since the vital blood-forming organs are particularly sensitive to radiation injury. *For example, when a man receives a total body dose of 200 to 400 r,* 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 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.

A late effect of radiation appears to be leukemia, which may arise years after radiation exposure. This disease, relatively rare in man, may show manifold increase in population groups, such as bomb casualties, subjected to intensive radiation over a short period of time or in those whose professional work has exposed them to higher than acceptable permissible doses.

In a British study, the incidence of intrauterine exposure to X-rays used to take roentgenograms was determined in two groups of children, one dying of leukemia and other cancers and the other without malignant diseases. It was observed that a larger proportion of the former group were so exposed. Of several regional studies in America, some confirmed these observations but others have not. Because of difficulties inherent in epidemiological studies of this type, particularly with regard to the selection of non-irradiated controls, it is felt that further investigation will be required to establish whether or not diagnostic radiation is leukemogenic to human embryos.

Gastro-intestinal Tract: 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. 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 *a person's whole body is exposed to 200*

** An interim statement of the Subcommittee on Acute and Long-Term Hematological Effects is presented in Appendix A herewith.*

to 400 r radiation, more serious effects occur. Failure of the cells lining the intestine to replace themselves results in *partial* denudation of the surface, with loss of fluid and salts; complicated by ulcerations, spread of infection, and bleeding.

When several thousand roentgens are given in divided doses, later effects are seen such as overgrowth of connective tissue (fibrosis) and decrease in the number of functioning epithelial cells. Cancer has occurred in animals given *very* large doses of isotopes in insoluble form by mouth.

Skin: Effects of radiation on skin have been widely observed. On the first day *after doses of a few hundred roentgens,* 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*er* doses. *Years* later, atrophic changes *may be* 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 *natives who were exposed to fallout in 1954 and received* 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, but serious after effects are not anticipated. Loss of hair was temporary in these persons. *Much heavier doses would be* required to *cause permanent loss of hair.* In animals, destruction of the pigment cells *by radiation* 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 *in doses exceeding several hundred roentgens.* Late effects are seen in radium poisoning, where there is repeated destruction and repair *at the sites of deposit of the radium in the bone* culminating in destructive changes in which bone sarcoma is likely to appear.

Lung*: Early after large doses *there is* 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 *certain* mining areas where large concentrations of radon *gas and its disintegration products* were inhaled *by miners over a long period of time.*

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 *to carcinogenesis.*

Eye: *Cataracts in man have resulted from injudicious exposure to X-rays, gamma rays, beta particles and neutrons. The threshold for cataract production from X-rays (200 kv) is 600 to 1000 r. For equal energy absorbed in the tissue, the neutrons are more cataractogenic by a factor of 5 to 10. Keratoconjunctivitis also results from exposure to ionizing radiations, but the threshold is several times greater than is necessary to cause cataracts.*

Gonads: *A single sublethal radiation dose to a male may result in sterility after a few weeks, followed by a slow recovery. Chronic exposure 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 occupational permissible dose rate. Larger doses (above 800 r to the gonads) may permanently sterilize men and*

* An interim statement of the Subcommittee on Inhalation Hazards is presented in Appendix B herewith.

women. Radiation administered locally to the testes in doses which would be sublethal if administered to the whole body may cause considerable degrees of irreparable injury in the sperm-producing tissues; and in persons who had only borderline fertility before exposure, permanent infertility or subfertility may result. Limited experience with the Marshall Islanders, the exposed Japanese, and certain accident cases suggest that substantial fractions of the midlethal dose for man (around 400 to 600 r) did not have serious permanent effect on fertility. However, gonadal doses are not known with certainty in these cases and the numbers of such cases studied extensively for this purpose for a long period of time after exposure have been few.

Central Nervous System: *The adult nervous system may be affected by ionizing radiations in several ways. In the course of conventional cancer therapy, when parts of the nervous system must be exposed, several thousand roentgens may permanently injure the blood vessels of the brain or spinal cord, leading to ischemic damage. Many thousands of roentgens when delivered rapidly may quickly destroy certain elements in the central nervous system or, in other instances, so derange the function of vital centers as to cause death at once. Doses in the hundreds of roentgens seem to have little measurable effect on adult nervous tissues. Recent reports that subtle functions of the brain are disturbed by doses of a few roentgens still await confirmation.*

Embryonic Development: *Mammalian embryos are readily affected by low doses of ionizing radiations. In laboratory mammals with certain genetic traits, as little as 20 r may alter development. Doses of 100 to 300 r cause a predictable spectrum of malformations depending on the stage of development of the embryo when exposed. These malformations can be well understood in terms of classical experimental embryology. High doses are generally lethal to embryos. Little is known about the effects of radiation on man during early development except that malformation or death follows irradiation of embryos in a dose range comparable to that known to harm other mammals. Virtually nothing is known about the effects on late fetuses, and scarcely more regarding the effects of exposure of infants and children on subsequent development.*

Studies of possible correlation of the frequency of congenital abnormalities with levels of natural radiation have been suggested. While one survey has been interpreted to show increase of congenital malformations in areas relatively high in natural radioactivity, more detailed and better controlled studies will be necessary before it can be concluded that these low doses of radiation are capable of producing human anomalies.

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

Factors Influencing Sensitivity: Very young or very old animals have increased sensitivity to lethal effects, *and there is some experimental evidence to indicate that in some species the 50% acute lethal dose (LD_{50}) may decrease progressively with increasing age during adult life, while in other species a decrease in LD_{50} may not be observable until later life. Information about the influence of genetic constitution on radiation effects is meager at present, most of the research on the problem having been done on genetically homogeneous or "inbred" mouse strains. In the mouse data it seems that there is a nonspecific component of life shortening that is comparatively independent of genetic makeup, and in addition a specific component, reflected particularly in susceptibility to leukemia, which varies from strain to strain. The contribution of these strain-specific diseases to the total mortality is greater in the mouse than in other species on which information is available, but in spite of this the range* *of variation in overall life shortening between strains is less than a factor of two. There is as yet no way to determine what the genetic heterogeneity of a human population signifies in terms of differences in radiosensitivity between members of the population. The evidence of ethnic differences in the incidence of spontaneous leukemia suggests that in man, as in the mouse, genetic constitution will play a role in the susceptibility to radiogenic leukemia. The consistency of the experimental data and estimates suggests that the nonspecific life shortening action has a common basis in all mammalian forms that may be conceived to be in cellular and subcellular mechanisms that exhibit little genetic variability.*

There may be a correlation between "vigor" or "fitness" and acute radiosensitivity in man, as there is in experimental animals. Judgments about the effect of physical or clinical status or pre-existing disease, etc., on short- or long-term effects of radiation must be based at present almost entirely on incidental clinical and experimental observations, because only the barest beginnings have been made on the study under controlled conditions of the influence of nutrition, exercise, disease, and other environmental and physiological variables on radiation effects. It is common knowledge that any of a variety of stresses can have an activating effect on chronic or latent disease. Radiation can have such an effect on certain diseases.

Cancer: 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.

All types of induced and spontaneous tumors appear not to arise at once, but to pass through a series of preliminary stages; radiation-induced tumors often take a particularly long time to develop. *They do not begin to develop immediately after the radiation has altered the cells. There is much evidence indicating that malignant change ordinarily develops only after a series of "precancerous" changes or a state of tissue disorder has taken place. This tissue disorder need not exist at the site of origin of the cancer, as there are examples of the radiation-induction of malignant disease through physiological or hormonal mechanisms which are clearly indirect, i.e., where irradiation of the cells of origin is clearly not the critical factor.* 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.

Some recent reviews have expressed the opinion that the incidence of tumors induced in a population may bear a direct proportion to radiation dose, based on the somatic mutation theory. So far it has been impossible to test this on human populations and in general animal experiments have shown that the picture may be much more complicated. It has been suggested by others that amounts of radiation below a certain threshold quantity may have no effect at all. It is conceivable that very small doses of radiation might induce tumors, but in a much lower incidence than would be predicted by the theory of proportionality. This would be true if somatic mutation was a part of the cancer induction process, but played a minor role. In view of the many uncertainties, the Committee does not consider it justifiable to predict human tumor incidences from small radiation doses based on extrapolation from the observed incidences following high dosage.

Radioactive Fallout: Data on Rongelap inhabitants and Japanese fishermen indicate that during exposure to radioactive fallout the amount of radioactive material deposited within the body may barely exceed permissible levels at a time when exposure to external radiation has reached a considerable proportion of the lethal dose.

There are two notable instances of isotopes occurring in fallout that are much less concentrated in the gonads than they are in some other tissues, so that somatic damage might occur relatively in excess of genetic damage. Widespread contamination with strontium-90 *or with radioactive iodine results, respectively, in radiation to the skeleton and nearby tissues and to the thyroid gland. These two isotopes are at present being measured in samples of foodstuffs, including milk which in Western countries appears to be the major vehicle for their uptake in man. Levels have been increasing in the past few years but remain well below those that need to be considered cause for alarm.*

In relation to world-wide contamination, food chains are important. Fallout contaminates plants through ground and leaf deposition; animals eat these plants, *and secrete some isotopes in milk. The relative importance of foodstuffs in introducing radioactive isotopes in man depends, of course, on each individual eating habit. In this country milk and cheese are chief sources of calcium and of radio-strontium contaminants.* Throughout this *food* 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.*

Therapy of Radiation Injury: While treatment is difficult, some success has been achieved with antibiotics and properly timed blood transfusions, *and it now appears that transfusion of bone marrow may have value in the treatment of single overexposures.* 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.

In summary, it seems that the limitations of exposure suggested by the Committee on Genetics should be adequate for purposes of establishing that no perceptible somatic effect will occur, although theoretically minor shortening of life span or a slightly increased incidence of tumors cannot be excluded as a possibility.

SHIELDS WARREN, *Chairman*
HOWARD L. ANDREWS
AUSTIN M. BRUES
HENRY A. BLAIR
JOHN C. BUGHER
RICHARD H. CHAMBERLAIN
EUGENE P. CRONKITE
CHARLES E. DUNLAP
JACOB FURTH
WEBB HAYMAKER
LOUIS H. HEMPELMANN
SAMUEL P. HICKS
HENRY S. KAPLAN
HARRY A. KORNBERG
SIDNEY C. MADDEN

* See 1960 Summary Report of the Committee on Effects of Atomic Radiation on Agriculture and Food Supplies.

APPENDIX A

Interim Statement of the Subcommittee on Acute and Long-Term Hematological Effects

THE Subcommittee met in St. Louis, Missouri, November 20–21, 1959. The problems discussed were (1) detection of the effects of low-doses of radiation by hematologic means, and (2) the quantitative relationship between exposure to radiation and the increased risk of leukemia. The present acceptability of the 1956 Subcommittee Report* was also discussed; it was the unanimous opinion that, rather than undertake an extensive revision, a new report should be prepared summarizing the current status of the problems cited, and incorporating any new information that is available.

The Subcommittee agreed unanimously that chronic exposure to radiation is a major problem. Serious efforts should be made to determine the total morbidity and mortality associated with continuous or repeated exposure to small amounts of ionizing radiation. Estimates of the risk of leukemia (and other hematologic diseases) should be based on the best data available at the time in question. Hopefully, successive approximations, based on data which are more and more nearly complete, will make it possible to estimate risks after permissible doses with greater assurance than is presently possible. Leukemia is an appropriate subject on which to base estimates of maximum permissible dose because some quantitative human data are available. However, the data are limited to (1) the effects of acute single doses in the Japanese, and (2) the effects of therapeutic irradiation for spondylitis. The presently available data on radiologists and on children in whom the thymus was irradiated confirm the fact that radiation is leukemogenic, but contributes little to an understanding of the dose-effect relationship. The leukemia which has occurred in a small fraction of patients treated with I^{131} needs to be evaluated critically. The cardinal advantage of the human leukemia data is that some quantitative data, incomplete though they may be, are available on which to base predictions. It is possible to estimate the increased risk of leukemia following single doses in the range of approximately 50–100 rads to the highest dose after which there is survival. There is uncertainty as to the absolute value of estimates of doses at Hiroshima and Nagasaki. The 50–100 rads mentioned may be significantly revised in the future with the acquisition of new data. Predictions of this sort are not at the present time as practical with respect to life shortening, other cancer, and cataracts.

Prediction requires evaluation of the possibility that there is a threshold dose below which there is no probability of inducing leukemia, a concept which implies a factor of safety that would be most reassuring to those who are exposed to radiation in excess of the natural background as well as to those who must make policy decisions. Some members of the Subcommittee believe, on the basis of analogy to radium data and chemical poisons, that there must be a threshold; however, no member of the Subcommittee feels that he can estimate the

---

* NAS—NRC Publication 452, *Pathologic Effects of Atomic Radiation,* 1956.

size of the threshold or, for that matter, even prove its existence. Accordingly, the Subcommittee believes it is prudent to assume that there is no threshold.

The Japanese single-dose whole-body data are sufficiently extensive with respect to size of the population at risk and the range of doses to be useful for predicting the incidence of leukemia after single doses. In this range, the incidence increased with dose and the relationship is approximately linear. Among the Japanese exposed to doses believed to be less than 50–100 rads, the occurrence of leukemia since 1945 is not significantly greater than in the general population. Since this group of survivors (i.e., less than 100 rads) is the largest group available for study, the failure to observe an increase in the rate of leukemia is of interest. In the range of exposure dose where leukemia was increased, the relationship to dose can be expressed as equivalent to 1 case per 10^6 people at risk per rad per year. The Subcommittee feels that, in this dose range, fairly accurate predictions can be made after single doses of radiation, and for the time interval (about 15 years) corresponding to the interval since exposure in Japan. The Subcommittee is not willing to accept the assumptions of E. B. Lewis and others that: (1) there will be a continued constant incidence of leukemia per rad exposure for the duration of life, (2) the incidence will be identical for acute and chronic exposure (i.e., no dose-rate dependence), and (3) it is possible to predict the incidence of leukemia on the basis of estimates of the absorbed dose due to radioisotopes such as SR^{89-90} or radium deposited in the bones.

Available studies of man and of experimental animals, following chronic exposure to external sources of radiation or after the internal deposition of radioactive materials, provide no basis for predictions of the incidence of radiation-induced leukemia. In fact, the data of Mole on the induction of leukemia in mice suggest that chronic exposure at low dose rate is less efficient than acute exposure in this respect.

The majority of the cases of leukemia attributed to radiation in the Japanese survivors and in the British spondylitics have been of the myelocytic variety. Estimates of the radiation dose to the bone marrow carry the implication that it is the vulnerable tissue. It is of interest that no cases of chronic lymphocytic leukemia in man have been attributed to prior radiation exposure. It is possible that some of the cases of leukemia in children subjected to irradiation of the thymus in infancy may have been of the acute lymphocytic type. Myelocytic leukemias are presumably induced only by irradiation of large segments of the bone marrow.

At the present time it is not possible to attribute to radiation exposure the increased incidence in leukemia which has been reported in several countries including the United States. One reason is the fact that a substantial portion of the increased incidence is due to chronic lymphocytic leukemia, the occurrence of which has not yet been shown to be influenced by ionizing radiations. Another reason is the fact that there are many toxic substances in the modern environment which have not been evaluated adequately with respect to their influence on leukemogenesis even though some of them (e.g., benzpyrene, arsenic, etc.) are carcinogenic in laboratory animals and in man.

Another problem of interest to the Subcommittee is the possibility of detecting low doses of radiation by hematologic means. This is a very important, unsolved problem which the Subcommittee believes to have a high priority. To date the enumeration of binucleated lymphocytes appears to be the best available indicator. However, at the present stage of development it is not very practical for widespread application because of the large number of cells that must be scored visually. There are some indications that electronic methods of scanning can be developed. The Subcommittee recommends that research and development along these lines be intensified.

This interim statement has been prepared at this time to indicate the current concern of the Subcommittee on the leukemogenic properties of radiation and detection of low exposure. A more extensive report is in preparation.

EUGENE P. CRONKITE, *Chairman*
VICTOR P. BOND
JAMES B. HARTGERING
MARYLOU INGRAM
GEORGE V. LEROY
WILLIAM C. MOLONEY
CARL V. MOORE
ROBERT D. MOSELEY, JR.
JOHN H. RUST
MARVIN A. SCHNEIDERMAN
FREDERICK STOHLMAN, JR.
CARL F. TESSMER

APPENDIX B

Interim Statement of the Subcommittee on Inhalation Hazards

ON January 11–13, 1960, the Subcommittee on Inhalation Hazards met in Richland, Washington, to prepare the final draft of its new report on Effects of Inhaled Radioactive Particles. The following statement is the concluding chapter of the report, and may be considered as the conclusions and recommendations that were approved by the Subcommittee. It is expected that the complete report will be available soon for publication and general distribution.

A general review of available information has been made to define the potential hazards of inhaling radioactive particles. Included in the forthcoming report of this Subcommittee are discussions on the properties and sources of radioactive particles, the relevant physiology of the respiratory tract, the probable mechanisms of deposition of particles in the respiratory tract and their removal from the tract, pathological effects from external sources and of deposited material, and finally, the application of these factors to assess the possible damage due to inhaling radioactive particles. In general, the conclusions support those given in the 1956 report of the Subcommittee.* Additional information obtained since that time has served to emphasize the importance of the problem and to point out the areas where information is most needed. Answers to the problem of evaluating inhalation hazards are still tentative, especially with respect to long-term effects.

* NAS—NRC Publication 452, *Pathologic Effects of Atomic Radiation*, 1956.

A. *Sources*

1. Human beings have always been exposed to airborne particles which contain naturally occurring radioelements.

2. The greatest occupational exposures to lungs of individuals have occurred among miners of ores containing radioactive minerals and among some workers in ore processing and in manufacturing industries that utilize naturally occurring radioelements.

3. Fallout from nuclear weapons testing to date raises the inhalation exposure of human populations to radioactive particles only slightly.

4. An increased potential for exposure to radioactive aerosols in an expanding atomic energy economy occurs in the processing and use of nuclear fuels and fission products.

5. Other possible sources are the varied applications of radioelements in agriculture, industry, medicine, and research.

B. *Behavior*

1. Deposition and retention of inhaled radioactive particles are related to their physical and chemical properties, and the physiological and anatomical characteristics of the host.

2. For different radioactive particles, retention in the lung, translocation to other tissues, and excretion have not been successfully generalized by a single mathematical model.

3. The concentration and retention of radioactive particles are often such that higher radiation doses may be delivered to organs other than the lung.

C. *Effects*

1. Biological effects caused by radioactive particles deposited in the respiratory tract depend upon the radiation dose delivered to the tissue, the responsiveness of the tissue, and the type of radiation.

2. Whether alpha emitters are retained in the lungs or translocated to other sites, the direct radiation effect is confined to cells immediately adjacent to sites of deposition. The more penetrating radiation from beta and gamma emitters will affect tissues at greater radii from sites of deposition.

3. In humans, the principal effects of radiation to the respiratory tract are pneumonitis and fibrosis; and in experimental animals, also carcinoma.

4. Recent findings on the accumulation of radioactive material in the tracheobronchial lymph nodes have pointed to their increased importance in evaluating inhalation hazards.

5. In experimental animals, the mean lung radiation dose that appears to induce tumors is about 1000 rads, assuming uniform distribution. But due to non-uniform distribution, with some loci receiving orders of magnitude more radiation, this point is yet to be clarified.

6. The effect of age and condition of the lung on retention and translocation of particles and on the sensitivity of lung tissue is not known. These variables may markedly influence the effects of inhaled radioactive particles.

D. *Evaluation*

1. During the first few weeks following contaminating nuclear detonations, the radiation dose from external exposure of the body to beta and gamma emitters in fallout usually far exceeds the internal radiation dose from inhalation of the same radionuclides.

2. We believe that the atmospheric content of radioactive particles from fallout originating from all previous nuclear tests presents a considerably smaller radiation exposure to the lung than does the average natural radon concentration in the air.

3. Under certain circumstances involving either acute or chronic inhalation exposures to long-lived fission products and/or alpha particle-emitting fissionable materials, their pulmonary retention could give large and potentially carcinogenic focal exposures to the respiratory organs while subjecting the individuals to minimal external beta-gamma radiation exposures.

4. The evidence for induction of cancer by inhaled radioactive materials in experimental animals is convincing. There is no reason to think this cannot occur in man despite the lack of definitive evidence at present. Therefore, continued study of inhalation hazards is urgent, and the continuation of stringent environmental control measures is justified pending the completion of adequate studies.

E. *Research Needs*

1. Inhalation studies with specific radionuclides should be continued in several species of animals in order to better define deposition, retention, clearance, turnover, and biological effects.

2. The influence of pre-existing pathological processes on deposition, clearance, and retention of particles in both upper and lower respiratory tract should be determined.

3. Information is needed on the relative biological effectiveness of various radiations in causing late injury such as cancer.

4. Possible synergism between radiation and chemicals should be studied.

5. Better instrumentation is needed for measurements of solubility, and of particle size and distribution of radioactivity on particles in the 0.05- to 50-micron size range, in order to correlate physical properties with observed biological effects. The instruments should be usable in the field as well as in the laboratory.

6. More information should be obtained on the physical and chemical properties of small particles.

7. Better methods are required to estimate lung burdens in humans.

8. Programs should be considered for measuring concentrations of radionuclides in human tissue where there is reason to believe there was significant exposure to radioactive particles.

9. The least effectively controlled inhalation hazards from radioactive materials appear to be those associated with radon and daughter products in mining operations. Efforts to control this hazard should be intensified.

10. Since knowledge of the effects of inhaled materials is rapidly expanding, reconsideration of these recommendations should be made from time to time as new information is acquired.

HARRY A. KORNBERG, *Chairman*
W. J. BAIR
STANTON H. COHN
C. C. GAMERTSFELDER
J. W. HEALEY
FRANCIS R. HOLDEN
JAMES K. SCOTT
J. NEWELL STANNARD
GEORGE V. TAPLIN

Report of the

COMMITTEE ON METEOROLOGICAL ASPECTS OF THE EFFECTS OF ATOMIC RADIATION

REPORT OF THE
COMMITTEE ON METEOROLOGICAL ASPECTS

I. Preface

THIS report is intended as a supplement to the Committee's 1956 Summary Report and deals with a problem which has received our major attention and which has been a matter of intense public concern for the past few years—the meteorological aspects of world-wide fallout. This does not imply that significant progress has not been made with other problems or that other phases are less important. For example, considerable experimental and theoretical effort has been expended on the problems associated with gaseous and particulate effluents from nuclear reactors, and it is felt that these problems will become increasingly important with the rapid development of nuclear technology. Also, some very recent work using natural radionuclides as atmospheric tracers has opened new avenues for meteorological research. New proposals involving the use of nuclear explosives for weather modification and research have been advanced recently. These proposals should be carefully studied, both for their technical feasibility in accomplishing the desired results and for side effects such as further contaminating the atmosphere. The present state of knowledge does not seem to warrant the use of nuclear explosions for meteorological purposes. Finally, although there has been much speculation about the influence of atomic testing on weather, there still appears to be no additional evidence suggesting a cause and effect relationship.

II. Introduction to the Fallout Problem

The detonation of a nuclear device normally results in the release of radioactive isotopes into the atmosphere. Of greatest concern in the problem of world-wide fallout are the longer-lived fission products, particularly strontium-90 (Sr^{90}) with a radioactive half-life of 28 years, and cesium-137 (Cs^{137}) with a 27-year half-life. Attention has also been directed to carbon-14 (C^{14}), a 5,600-year half-life radioisotope which both occurs naturally and results from nuclear detonations.

The airborne radioactive particles from an atomic explosion are normally classified, according to their history, into three categories: local, intermediate, and delayed. *Local* fallout consists principally of the larger particles that are deposited in the vicinity of the burst and does not significantly influence the world-wide patterns. The fraction of the radioactivity produced which falls out locally varies from virtually none in the case of air bursts high above the ground to almost all in the case of ground surface or subsurface bursts. *Intermediate* fallout comprises that debris which remains airborne on the average for several weeks and is composed primarily of particles left in the troposphere after the nuclear cloud has stabilized. The troposphere is the layer of air extending from the earth's surface to about 35,000 feet in temperate and polar regions and to about 55,000 feet in tropical areas. The troposphere contains our everyday weather, clouds, and precipitation. Tropospheric debris is deposited in the general latitude of the test, since east-west motions in the atmosphere predominate over north-south motions and the tropospheric residence time is short.

Delayed fallout, the primary concern of this report, originates from the portions of nuclear clouds which penetrate into the stratosphere. This is a region above the troposphere, separated from it by a discontinuous interface called the tropopause. The emphasis on delayed fallout arises because it constitutes the bulk of the world-wide fallout, and at this time is the major source of artificial radioactivity left in the atmosphere. This will continue to be the case unless large-scale testing is resumed. As a result of recent findings indicating the short storage time of some stratospheric debris, the distinction between intermediate and delayed fallout is not as clear-cut as was formerly considered.

The fission products comprising delayed fallout and probably much of the intermediate fallout are in very small particles. Recent evidence tends to confirm the fact that most stratospheric debris is on particles smaller than 0.1 micron (0.000039 inches). It has also been observed that most of the Sr^{90} and Cs^{137} is in soluble form.

Carbon-14 results from the interaction of neutrons produced in a nuclear explosion with atmospheric nitrogen. It normally combines into carbon dioxide, or possibly carbon monoxide, natural gaseous components of the atmosphere. Undoubtedly some C^{14} falls out locally as calcium carbonate and some remains in the troposphere, but measurements indicate that the excess over the natural background cannot be associated with tropospheric fallout.

III. Recent Observations

The number and variety of measurements of long-lived fission products and of C^{14} made in the past few years are sufficient to provide a description of the important features of world-wide fallout. These measurements include extensive Sr^{90} soil analyses over all parts of the world, utilizing improved techniques and quality controls which permit increased confidence in the data. Networks for collecting and analyzing precipitation for Sr^{90} have become much more widespread and are using ion-exchange techniques for extracting the strontium from the precipitation. Systematic measurements of the air concentration of fission products have also increased and monthly profiles of the concentration of several specific isotopes along the 80°W meridian have proved valuable in studying large-scale phenomena. Some progress has been made in studying fallout over the 70% of the globe covered by water. Measurements of Sr^{90} in surface and deep waters indicate that much of the strontium remains in the upper mixed layers. Because of the movement of ocean waters, and of some mixing into deep waters, interpretation of these data in terms of world-wide fallout is difficult. Collections of precipitation aboard U. S. ocean weather ships and of precipitation and soil samples on islands have also contributed to our understanding of fallout over the oceans. It is assumed that fallout over the oceans tends to parallel that over land at similar latitudes. An unsolved problem remains in the sampling of snow. This is particularly important in polar regions where it is difficult to distinguish between fresh and old blowing snow. Impetus for expanding radioactivity measurements and for collecting and collating data has resulted from the International Geophysical Year program. Various measurements of C^{14} in air, water, and vegetation show the growth of this isotope in our environment as the result of nuclear testing.

A very useful series of measurements for studying large-scale circulation features in the atmosphere resulted from the unique production of tungsten-185 (W^{185}) in the Pacific test series held by the U. S. in the summer of 1958. Measurements made more than six months after the end of the test series confirmed earlier speculations concerning the poleward drift or mixing of equatorial stratospheric injections. In both fallout and ground-level air, higher concentrations were observed in north temperate latitudes than in tropical or southern latitudes.

An area of particular importance in understanding global fallout is the distribution and movement of debris in the high atmosphere. Unfortunately, sampling in the stratosphere is difficult. Many more measurements are needed to further our understanding of stratosphere circulations and stratospheric-tropospheric exchange phenomena. However, significant progress has been made. Balloon sampling of particulates over one southern and three northern hemisphere stations up to altitudes of 90,000 feet has given a gross picture of concentrations of fission products in the stratosphere, although the technical difficulties render the results somewhat uncertain. Data from a similar program to collect C^{14} from the stratosphere have also been reported. In addition, the lower stratosphere has been systematically probed by aircraft; the resulting data, in conjunction with that from balloons, has made it possible to estimate the fission-product content of the stratosphere.

IV. Analysis and Interpretation

The observations mentioned above, together with earlier data, have given us the following broad picture of world-wide fallout:

1. The non-uniform distribution of Sr^{90} fallout, suggested in 1956, has been confirmed and the principal features are shown by the solid curve in figure 1. (This curve is based on the 1958 soil results, corrected to a common date, November 1, 1958, by means of observed precipitation and fallout data.) There is a maximum in the 40°–50°N latitude band, a suggestion of a secondary maximum in the same latitudes of the southern hemisphere, and minima in the equatorial and polar regions. A similar pattern exists in the specific activity of Sr^{90}, the amount of Sr^{90} fallout per unit area per inch of rain.

2. The concentration of Sr^{90} in the air and in precipitation exhibits a seasonal trend in the temperate zones, the highest values being observed in the spring and the lowest in the fall. This trend has been marked in the United States and in western Europe, and is somewhat more nebulous in the southern hemisphere and elsewhere in the northern hemisphere.

3. An analysis of short-lived fission products and estimates of the production of tropospheric debris indicates that 90% or more of the long-lived fallout originates from the stratosphere. Possible exceptions are in the areas downwind of test sites. Soil data in the United States suggest an influence from the Nevada Test Site for several hundred miles in the downwind direction.

4. All stratospheric measurements of fission products and C^{14} indicate a non-uniform distribution of contaminants, both on a hemispheric basis and in smaller scale terms. In mid-1958, the northern hemisphere stratosphere contained about two to three times as much debris as the southern hemisphere stratosphere because of more testing in the northern hemisphere. Inhomogeneities are found in each hemisphere.

5. Non-local fallout, both tropospheric and stratospheric (intermediate and delayed), is deposited primarily by precipitation. Most observations suggest that on the average dry fallout is of the order of 10% or less of the total deposition.

6. While the average specific activity of Sr^{90} is observed to be reasonably constant in the same climatic region, it is higher in arid regions than in rainy areas at the same latitude.

Some progress has been made in the past few years in determining the residence time of debris in various parts of the atmosphere. It is generally agreed that the half-residence time of radioactive particles in the troposphere is of the order of two to four weeks. It is likely that the exact value depends on the location relative to the removal processes. Particles in or below the rain-producing levels will survive for a shorter time than those in the upper troposphere.

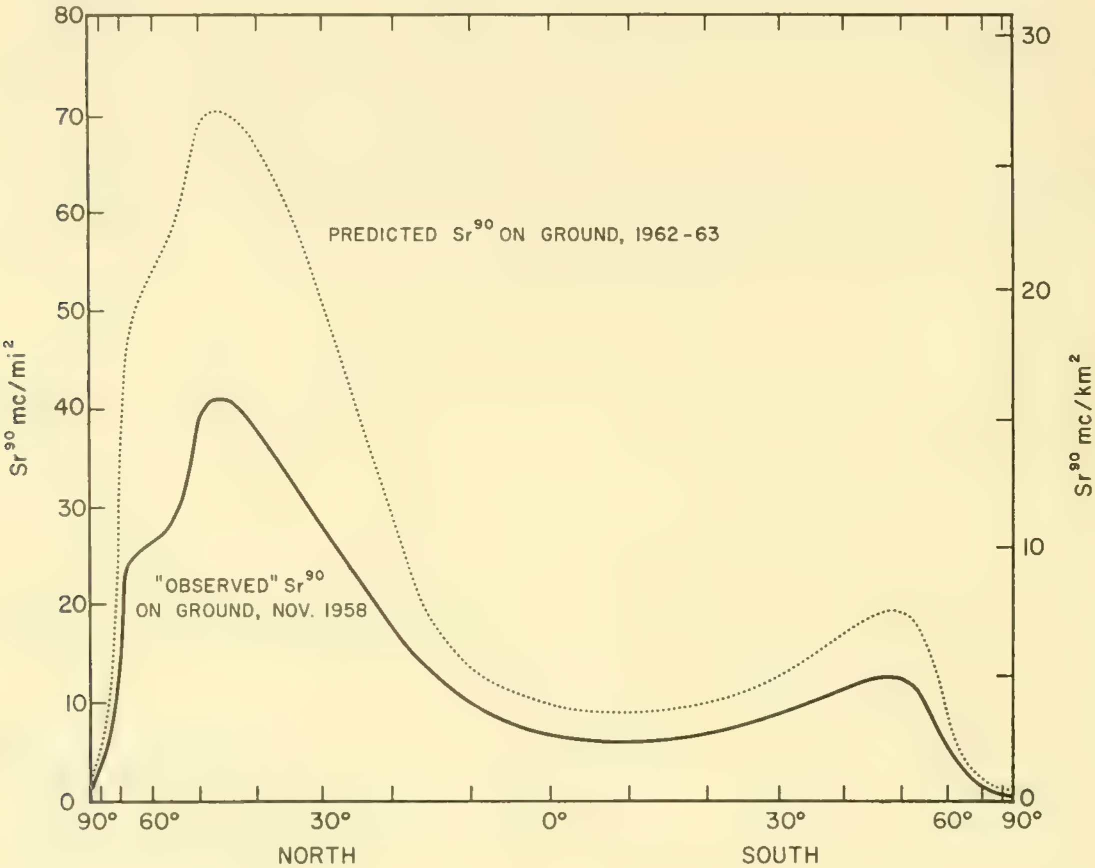


Figure 1

Significant new knowledge has been obtained on the storage times of stratospheric debris. It is now generally recognized that the concept of a fixed fractional removal rate from the stratosphere is untenable and that the removal rates depend on the latitude and altitude of injection of the debris, the season, and upon stratospheric circulations, which have a spatial and temporal variability. As a first approximation, the idea of a variable mean storage time may be used. For equatorial injections the values range from about one to five years, the shorter times applying to the lower stratospheric injections; for temperate and polar latitude injections, the time is under one year. (These estimates do not apply to debris injected into the high atmosphere, above about 25 miles.) The shorter residence times make the contribution of shorter-lived isotopes in stratospheric fallout a more significant factor in environmental contamination than was previously thought.

Although there are still many unsolved problems concerning the exact mode of stratospheric transport and of the locale and mechanism of removal processes from the stratosphere, the consensus is that a poleward transfer takes place in the lower tropical stratosphere and that removal of both equatorial and polar stratospheric radioactivity occurs primarily in temperate and polar regions.

V. Future Fallout

The long-lived fission products in the atmosphere in November, 1958, can be estimated in two ways, each involving approximations and assumptions which cannot be completely verified. The estimates are in fairly good agreement. The usual approximation concerning the production of Sr^{90} is:

1 megaton of fission yield = 0.1 megacurie of Sr^{90}
= 0.5 millicurie per square mile of Sr^{90} if uniformly distributed over the globe.

The Atomic Energy Commission has announced that as of November, 1958, a total fission yield of 92 megatons or 9.2 megacuries of Sr^{90} has been released into the atmosphere. Of these, it is estimated that about 4.0 megacuries are contained in local fallout and are therefore unavailable for world-wide distribution. This estimate is uncertain and represents the weakest link in the computation of the amount still in the atmosphere. Using the 1958 soil analysis in figure 1, it is estimated that 3.0 megacuries have already been deposited over the world exclusive of local fallout. This leaves a residual of 2.2 megacuries (less decay since time of formation) still in the atmosphere as of November, 1958. An alternative computation involves an estimate of the atmospheric content based on balloon and aircraft observations. From the limited data available, it is estimated that in July, 1958, there were 1.0 megacuries of Sr^{90} in the stratosphere. In the period from July to November, it is estimated that 1.5 additional megacuries were injected into the atmosphere by the U.S.S.R. test series, resulting in a total of 2.5 megacuries in the atmosphere in November, 1958.

The future distribution of the debris still in the stratosphere can be predicted from a knowledge of the distribution of debris already deposited. The dotted curve in figure 1 shows the expected distribution of Sr^{90} on the ground in 1962–1963, assuming no additional injections after November, 1958. This curve is based on the aircraft and balloon data (which indicate a distribution of 0.7 megacuries of Sr^{90} in the northern hemisphere and 0.3 in the southern hemisphere in July, 1958); on an assumption that virtually all of the 1.5 megacuries added in the fall of 1958 remains in the northern hemisphere; on the expectation that future stratospheric fallout will parallel that in the past; and with an allowance for radioactive decay. Almost all the debris now in the stratosphere will have been deposited by 1962–1963. The predicted average peak of 70 to 75 millicuries Sr^{90} per square mile in the 40°–50°N latitude band may be increased by as much as 35 millicuries per square mile in the area downwind of the Nevada Test Site. The equatorial minimum is expected to be about 10 millicuries per square mile and the secondary peak in the southern hemisphere about 20 millicuries per square mile. Cesium-137 fallout should be similarly distributed, with the actual values about 80% greater.

The average concentration of Sr^{90} in ground level air reached a peak of about 10 to 15 disintegrations per minute per 100 cubic meters at some northern hemisphere stations in the spring of 1959. These are undoubtedly the highest values that will occur if no further testing takes place and will decline substantially from that time on. A smaller but detectable peak should occur in the spring of 1960 if theories concerning a spring maximum are valid.

The prediction of future C^{14} levels in the atmosphere is more complicated because of uncertainties in the rate of mixing of atmospheric carbon with the oceans. It is estimated that about 25×10^{27} atoms of C^{14} have been added to the atmosphere by all atomic tests to date. At most, the concentration of C^{14} in ground level air will increase by about 70% of natural background in the next few years. However, complete mixing with the surface waters of the oceans should reduce this excess to about $\frac{1}{3}$ of the natural background within a few decades; eventually mixing with the deep ocean layers will cause a reduction to 1% or less of the natural background, since deep ocean layers contain over 50 times more exchangeable carbon than the atmosphere.

VI. Conclusion

Although the prediction of future levels of artificial radioactivity given here is uncertain in detail, it is believed that the overall picture is becoming clearer. The next few years should see even more improvement in our understanding of world-wide fallout, particularly if no further testing takes place. Such phenomena as the postulated spring maximum in stratospheric fallout, the apportionment of debris between the northern and southern hemispheres, and the locations and intensities of stratospheric-tropospheric exchange processes will become better understood as observations now being made are processed and evaluated. Study of the distribution of tungsten-185 and rhodium-102 from the 1958 Pacific test series and additional soil and air concentration data will serve to clarify further many of the points of uncertainty, adding a new fund of knowledge to our understanding of atmospheric circulations.

HARRY WEXLER, *Chairman*
LESTER MACHTA, *Rapporteur*
CHARLES E. ANDERSON
R. R. BRAHAM, JR.
MERRIL EISENBUD
D. LEE HARRIS
B. G. HOLZMAN
H. G. HOUGHTON
W. W. KELLOGG
HEINZ LETTAU
ROBERT J. LIST
N. M. LULEJIAN
E. A. MARTELL

Report of the

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

REPORT OF THE COMMITTEE ON AGRICULTURE AND FOOD SUPPLIES

I. Introduction

THIS Committee issued a report in 1956 reviewing the diverse ways in which radiation or radioisotopes are of value or concern in agricultural research, agricultural production, and food processing. Since then, members of the Committee in their respective fields of competence have followed closely the developments in these areas of science and technology. Collectively they are in agreement that no major revision of their basic conclusions or recommendations is called for now; however, if they were restated, there might be some amplification and some changes in emphasis. There has been considerable progress in certain areas during the past three years. In general this has been unspectacular in nature, and a continuation of that process whereby research scientists in the laboratory or the field zealously fashion and incorporate into the great edifice of knowledge bricks of varied sizes and structural significance.

II. Radiation in Agricultural Research

We would like to reiterate our conviction that the contributions of radiation and of radioisotopes to agricultural production are coming primarily through acceleration in the progress of agricultural research. In recent years there have been great changes in the production of food for man and animals. The characteristics and the quality of crop and animal products have been modified and may be expected to be further altered as research specialists gain greater understanding of the physiology, biochemistry, and genetics of the basic biological events involved in crop and animal husbandry. The technology and economics of agricultural production similarly have undergone modification and will continue to be reshaped through refinement and greater control of the necessary practices.

III. Tracer Studies

In the improvement of the products of agriculture and, to a lesser but significant degree, in the modification of production practices, the use of various radioactive isotopes as tracers has continued to grow, and is likely to become increasingly rewarding as new, ingenious, and more discriminating techniques are devised. Studies involving the long-lived isotope of carbon-14 have already greatly extended knowledge of the cellular metabolic processes in plants, animals, and micro-organisms. Tritium labeling (hydrogen-3) of organic compounds, which is now coming into wider use, should extend and reinforce the carbon studies. The peculiar problems posed by biological systems, the wide range of isotopes now available, and the remarkable sensitivity of modern instruments, taken together, suggest that there is still much potential for development in the application of tracer techniques and molecular labeling.

IV. Evaluation of Research

In the United States, agricultural research is primarily supported by public funds, federal and state. In seeking examples of the returns from public expenditures which are in excess of 230 million dollars annually, attempts are sometimes made to put a dollar value on this or that item of expenditure or research, or this or that improvement arising from research. Sometimes this is relatively easy, as for example, when a wholly new product is involved. More often it is not possible because new knowledge does not stand alone but is incorporated in the previous structure. Much of the work involving radioisotopes and tracer techniques in agricultural research falls in this category. Advances, specifically aided or catalyzed through adoption of such techniques, can rarely be so clearly delineated that assessment in increased dollar income or improved production efficiency is feasible.

V. Radiation and Plant Mutation

In our earlier report we discussed at some length the use of radiation to induce mutants in plants and micro-organisms and the exploitation of this phenomenon in crop breeding programs. It was our considered opinion that while this placed a new tool in the hands of plant breeders, agronomically desirable new varieties are not likely to emerge by irradiation only, and that "mutation breeding" will not displace but will supplement the more conventional programs soundly based on known genetic principles. So far, very few new varieties of crop plants developed from radiation-induced mutants have in fact been released and accepted for wide planting by farmers. In general, the search to date has been concentrated on mutants having exceptional disease resistance, earliness, or, in cereals, strength of straw, because these are characteristics which are readily recognizable and urgently needed. The modification of other characteristics, perhaps less easily detected, may have greater potential in the long run.

Among microbiologists, radiation is becoming accepted as a routine means of inducing mutants of micro-organisms possessing different biochemical capabilities. Radiation techniques with this objective therefore find use in industrial microbiology on the one hand, and in basic studies of the metabolism and genetics of micro-organisms on the other.

VI. Radioisotopes for Physiological Research

Irradiation methods are not likely to be helpful in the genetic improvement of farm animals, except possibly with poultry, but substantial use of radioisotopes is being made in the investigation of problems of animal physiology and nutrition. We drew attention earlier to the research limitations presented by the problem of disposal of larger farm animals after use in experiments involving radioisotopes. Even when short half-life isotopes were used at tracer levels, the animals could not be marketed through the usual outlets. The Meat Inspection Division of the Agricultural Research Service, U. S. Department of Agriculture, after consultation with the Food and Drug Administration, has now established and published procedures for determining the acceptability of meat from animals which have been treated with tracer levels of radioactive isotopes for experimental purposes. The public welfare is fully protected in this measure.

VII. Control of Insect Pests

One unique use of radiation in the control of certain insect pests involves the release of males rendered sterile by radiation exposure. By 1956 a large pilot experiment on the island of Curaçao showed that the screw worm fly could probably be eradicated by application of this technique. Subsequent developments in the southeastern United States have amply confirmed this prediction. Releases of irradiated flies were started in January 1958 by the U. S. Department of Agriculture in Florida and were gradually extended into contiguous portions of southern Georgia and Alabama. Natural populations were reduced to a low level in southern Florida by the end of the year and at present many months have elapsed with only a single report of a screw worm case in the southeastern area where previously they were numerous and damaging. Although this technique is not applicable to all insect pests, similar attempts are being made to control the fruit fly in Hawaii and the Mexican fruit fly in the southern states.

VIII. Food Processing

In the field of food processing there has continued a broadly based program of research and development on techniques and facilities for the irradiation of plant and animal products to eliminate or reduce the microbial population. The potentialities of radiation preservation of foods are still not explicitly defined. The U. S. Army Quartermaster Corps has been the prime mover in this program and represents the keen interests of the military in these developments. Some considerations that are particularly weighty to the military are of less significance to the food industry or the consumer. However, an Interdepartmental Committee of various governmental agencies concerned with the possible extension of radiation preservation of food into the civilian economy is coordinating and monitoring these developments. Adoption for commercial food processing in the case of many items awaits the solution of problems of flavor, odor, texture, nutritive value, etc. that affect user acceptability, and of problems of comparative costs which will largely determine the economic acceptability of this new technological development.

Since the 1956 report of this Committee, some experimental food irradiations have been carried out under conditions which resulted in detectable amounts of induced radioactivity. At lower energies, adequate preservation conditions can be obtained without inducing a detectable activity. Feeding experiments in which animals have received irradiated foods have given some unexplained, anomalous results. These experiments must be repeated and extended.

IX. Fallout on Soil and Vegetation

In its earlier report the Committee dealt only briefly with the formidable array of problems presented as a result of the deposition of fallout elements in soil and vegetation, their accumulation in plants, and their transfer to plant and animal products used as food. It recognized that long sequences of fundamental chemical and biological processes are involved, and that the assessment of any ultimate hazard to man depends on quantitative information at each step in the chain, very little of which had actually been obtained. The immediately pressing issues relate to the incorporation into food of certain radioisotopes present in the fallout from weapons tests. Looking to the future, it is likely that products escaping or released from nuclear power or fuel-element processing plants may present analogous problems, which to a different degree may also arise from future industrial or agricultural uses of radioactive materials.

In the past three years much attention has been devoted to these matters, and many have been the statements on them in the press and elsewhere—some alarmist, some reassuring, some judicial, and some indefensible. The public may well be left with a feeling of dismay, because of the apparent lack of unanimity of opinion among those to whom it wishes to turn as experts. The difficulty confronting the scientist, however, is that many of the essential facts necessary to arrive at the answers sought are not yet available and, what is worse, are unlikely to be quickly available, despite his best efforts. Because he is under great pressure for an answer, he is forced uneasily into extrapolation or prediction. It is here that the grey areas of apparent disagreement develop. The chemist or physicist may not give sufficient weight to biological factors; the biologists, with as yet only vague understanding of the mechanism of radiation injury, even at levels where this is easily observed, is not ready confidently to predict or assess the effects of long exposure to very low levels of radiation from isotopes incorporated in the organism and perhaps continually presented in its food. Our colleagues on the Committees on Genetic Effects and Pathologic Effects are wrestling earnestly with these latter issues.

The levels that are currently present in agricultural products and food are very low; they are indeed measurable only because of remarkable developments in instrumentation. In most cases the measurement depends on the character and amount of radiation emitted; prior chemical separation may not be necessary or possible. The analytical procedures are expensive in man-hours and equipment; routine analysis or monitoring of all foods is not currently feasible. There has been debate and controversy as to the "permissibility" of the level of this or that isotope in food or water. Although this device may ultimately have merit in regulatory procedures, it is obviously inadequate in that, in considering the welfare of the consumer, it is the cumulative and retained isotope burden which must be weighed. Dietary preferences and differences in the geographic sources of foods will result in an infinitely complex pattern. The radioisotopes of greatest long-term concern are of course strontium-90 and cesium-137, which closely resemble in chemical properties the physiologically vital elements, calcium and potassium respectively. The cycling of these and other radioactive substances in the biosphere, through all plants, all animals, and all micro-organisms, presents biologists with a multitude of challenging problems of which the sequence through the agricultural domain forms only a small and not independent part. State and national boundaries have no meaning in relation to these events—every living organism, man included, now has a radioisotope burden higher and different from that in the pre-atomic eras.

Substantial progress, however, has been made at the technical level in the understanding of the mechanisms involved in entry and uptake of fallout elements into plants from either soil or leaf deposition; their movement in crop plants, their accumulation in those parts used for food by animals and man; their subsequent transfer, incorporation, retention, or excretion; and the equilibrium level that may be established. It is now recognized that fallout deposition in the northern hemisphere is quite variable, which means that the radioisotope levels of similar crop or animal products from different locations may vary considerably. The implications of this are of concern in view of the current inability to monitor all foods or food ingredients.

We are preparing a technical report in which we are bringing together much of the basic information about the sequence of events which results in the presence of fallout elements in crop and animal products. This will be directed primarily towards investigators in the agricultural and biological sciences in an attempt to define more clearly that which is known and to establish for them departure points on the frontiers of the unknown.

A. G. NORMAN, *Chairman*
C. L. COMAR
GEORGE W. IRVING, JR.
JAMES H. JENSEN
J. K. LOOSLI
R. L. LOVVORN
RALPH B. MARCH
GEORGE L. MCNEW
ROY OVERSTREET
KENNETH B. RAPER
H. A. RODENHISER
W. RALPH SINGLETON
RALPH G. U. SIU
G. FRED SOMERS
GEORGE F. STEWART

Report of the

COMMITTEE ON DISPOSAL AND DISPERSAL OF RADIOACTIVE WASTES

REPORT OF THE COMMITTEE ON DISPOSAL AND DISPERSAL OF RADIOACTIVE WASTES

I. Introduction

WITH an expanding nuclear energy industry, which has developed in a period of less than 15 years, it is to be expected that the management and control of radioactive waste materials will present new and increasing numbers of problems. As in a wide variety of heavy manufacturing industries, the treatment and disposal of waste materials from nuclear energy operations involve both environmental effects and technical processing problems. Moreover, because of the nature of radioactivity itself—including the long effective life of certain radioactive isotopes, and its non-destructibility—it is apparent that in the nuclear industry, complex and potentially far reaching legal and administrative problems in the management of radioactive wastes are involved. In waste disposal operations involving the controlled release of radioactive materials to the environment, the matter of public relations and the need for broad public understanding concerning the radiation hazards involved continue to be areas of immediate concern.

Because of the increasing public interest in the effect of all sources of radioactivity in our environment, a number of agencies of the public and particularly several committees of the United States Congress have held extensive public hearings related to this subject during the past year. The hearings on Industrial Radioactive Waste Disposal held before the Joint Congressional Committee on Atomic Energy in January and February, 1959, and in July, 1959, resulted in the most extensive compilation of information which has been published to date on this subject. This compendium is available as a valuable reference for the nuclear industry itself and for all agencies and organizations having a direct interest or responsibility in the control of radioactive waste materials. During the course of the hearings, existing waste disposal technology was reviewed, and the major waste problems facing the industry delineated. The status of research and development in the field was thoroughly discussed. It was noted that certain aspects of the problem, particularly in disposal of radioactive wastes into the seas and the operation of nuclear-propelled vessels, are being actively considered on an international basis by such agencies as the International Atomic Energy Agency, World Health Organization, Food and Agriculture Organization, and others.

Unfortunately, outside of the specialist group, the term "radioactive wastes" is generally considered under a single category without distinction as to the origin, nature, and quantity of the waste materials or the environment in which their effects must be evaluated. The word "radioactive" has thus become an all-inclusive term to the point where important characteristics of wastes such as *concentration* of radioactive material, *total quantity* of radioactivity, *isotopic composition* and *chemical* and *physical nature* often are overlooked. Yet these are the characteristics which, together with environmental, and including engineering and biological factors, provide the keys to waste management.

Three of the major factors in waste disposal operations are:

1. *The maximum quantity of various radioactive isotopes allowable in the human body or the various human organs.* This forms the basis for establishment of maximum permissible concentrations of various isotopes in air, water and food, and includes the ecological implications of biologic concentration of radioactivity by various organisms in our food chain and other highly important, complex, and in some instances unknown biological considerations. From an engineering standpoint, quantitative standards of permissible concentration of radioactive materials or, more importantly, standards of maximum permissible body burdens of radionuclides in air and water are necessary. Such recommended standards are contained in handbooks and publications of the National Committee on Radiation Protection and Measurements[1] and the International Commission on Radiological Protection[2], and are embodied for regulatory and licensing purposes in Federal[3] and various State regulations.

2. *The specific nature of the radioactive waste under consideration.* This is a highly variable factor which must be considered in specific, quantitative terms. It should be generally understood, for example, that there is little basis for comparison of waste management techniques or problems associated with the liquid wastes emanating from a normally operating water-cooled reactor, and those associated with the aqueous reprocessing of nuclear reactor fuels.

3. *The physical, chemical, and biological characteristics of the environment into which the waste is to be released.* Included here, again in specific, quantitative terms, is knowledge of or data on the atmosphere, the hydrosphere, and the lithosphere relating to dilution and/or concentration of radioactivity in the environment.

Essentially then, proper waste management consists of identifying and quantitatively describing items 2 and 3, and *their combined behavior*, to assure conformance with the standards established in item 1. A very important but sometimes unrecognized distinction is made between standards and the performance or operating criteria necessary to achieve these standards. For the most part, the standards are the result of the best available biological and medical knowledge and are of universal application. One should recognize, however, that due to lack of complete knowledge at the time the standards were formulated, there may be revisions in the standards and their application in the future. Accordingly, such standards must be considered subject to modification as more and better knowledge is gained and also, to some extent, to the degree of risk deemed acceptable under various circumstances. In any case, the recommended standards previously noted are generally accepted and should be used until additional information might indicate the need for revision. Because of the variability of wastes and environment, each waste disposal situation must be evaluated on an individual case basis. Generally the quantitative results of such an evaluation will *not* be universally applicable.

---

[1] Maximum permissible body burdens and maximum permissible concentrations of radionuclides in air and water for occupational exposure, *Recommendations of the National Committee on Radiation Protection and Measurements*, National Bureau of Standards Handbook 69, Superintendent of Documents, 1959.

[2] *Recommendations of the International Commission on Radiological Protection*, Pergamon Press, Inc., New York, 1959.

[3] Title 10, *Code of Federal Regulations*, Part 20, "Standard for Protection Against Radiation."

II. Present Status of Radioactive Waste Disposal

The following paragraphs summarize the status and latest developments in waste disposal operations:

1. To date, radioactive waste management operations have not resulted in any significant effect on the public, its environment, or its natural resources. Extensive and continuing monitoring programs will be required to assure that concentrations of radioactive material released in the environment do not become excessive. Recent indications of potential pollution of stream environments by the uranium milling industry show the need for a vigilant environmental monitoring program.

2. Treatment technology has been developed for removal of major portions of radioactive materials from *low-level* radioactive wastes, which have a radioactivity concentration of the order of fractions of microcuries per gallon. Wastes of this type can be expected in practically all nuclear energy operations. Treatment systems, involving such unit operations as evaporation, neutralization, chemical precipitation, and ion exchange have been satisfactorily utilized at various installations. In addition, depending on the type and quantity of radioactivity involved and the characteristics of the specific site environment, it has been possible to safely discharge low-level wastes, under careful control, directly to the environment (air, ground, and water) without treatment. Billions of gallons of such low-level wastes, mostly from certain major AEC centers, are produced annually and have been handled safely in this manner.

3. *Intermediate-level* wastes, with radioactivity concentrations in the millicurie-per-gallons range, have also been handled satisfactorily by existing treatment systems. In some instances, at AEC installations, wastes of this type so far have been amenable to ground disposal without treatment because of the particular environment at those locations.

4. *High-level* wastes, having concentrations of activity ranging up to hundreds or thousands of curies per gallon and widely varying chemical characteristics, are produced during the chemical reprocessing of irradiated reactor fuels. Since the beginning of the atomic energy program, approximately 65 million gallons of several types of these wastes have accumulated. At the present time, they are contained in underground tanks at the Hanford Works in Washington, the Savannah River Plant in South Carolina, and the National Reactor Testing Station in Idaho. Today, operating practice is directed at reducing the volume of high-level reprocessing waste in order to reduce tank storage requirements. It is a general consensus that tank storage is not an ultimate solution to the waste disposal problem but that interim (2–10 years) tank storage will be an integral part of any final disposal system.

5. Wastes resulting from normal reactor operations have not presented major technical problems to date. Treatment systems such as decay storage, filtration, evaporation, ion exchange, gas stripping, chemical precipitation, solidification of wastes, incineration, and dilution all have been utilized to process waste effluents in order that acceptable limits of radioactivity in the receiving environment would not be exceeded. Considerable operating data and experience for these waste handling facilities are available for plutonium production, and for research and test reactors located at various AEC installations. Operating data for power reactor waste handling systems is limited. Up to the present time, the Pressurized Water Reactor (PWR) at Shippingport, Pa., has been the major operating nuclear power station. Recently, the reactor installation at Dresden, Ill., was licensed to bring its power level up to 350 megawatts (50 per cent of its rated power).

In over-all power reactor operations, a major technological waste problem results from the chemical processing of irradiated reactor fuels. Present plans call for transportation of irradiated fuel elements from power reactor locations to AEC reprocessing facilities. Subsequently, the resulting highly radioactive wastes would be directed to underground tank storage.

The advancement of power reactor technology and more widespread geographical distribution of reactors may require further development of engineering criteria for the design, construction and operation of radioactive waste treatment systems for these facilities. Operating data for one year for the Shippingport station indicates that the waste treatment plant design and performance are such that only 1/10 to 1/100 of the quantity of radioactivity considered safe for dispersal to the environment is being discharged. Other power reactor waste treatment systems now under design and/or under construction are equally conservative. This point is further exemplified by the fact that neither ground disposal nor utilization of possible dilution capacity of receiving streams is presently planned for disposal of liquid wastes at large U. S. power reactor sites.

6. Rapid growth in the use of radionuclides in the fields of medicine, industry, agriculture, and research continues. During the past three years, the number of institutions using by-product (isotope) material has increased from 3200 to 4500, an increase of approximately 40 percent. In evaluating the potential or actual waste problems associated with the use of radionuclides, it should be noted that the bulk of the activity shipped from Oak Ridge National Laboratory is in sealed, essentially non-dispersable sources. Other laboratory uses of radionuclides involve experimental work utilizing microcurie or low millicurie amounts of material. In addition, radioisotopes are used extensively in medical diagnosis and therapy. The wastes resulting from these applications are generally of a "low-level" nature and disposal under the AEC regulatory program is carried out in accordance with established Federal regulations. Sealed sources that have decayed to a level of radioactivity that limits their further usefulness generally are disposed of by land burial at AEC installations.

III. Problem Areas Now Under Investigation

1. As previously indicated, the ultimate disposal of high-level liquid wastes associated with chemical reprocessing of irradiated nuclear fuel constitutes a major technological problem to be resolved in the waste disposal field. It appears, however, that during the next 5 to 10 years this problem will be restricted to a relatively few (probably less than five) AEC locations. Chemical reprocessing of power reactor fuels is currently under study by private organizations. The handling of the associated highly radioactive wastes will require detailed technical and administrative consideration. While tank storage represents an interim answer to the problem for the present and immediate future, it is the general consensus that such storage is not the practical, long term solution from an engineering standpoint. It is expected that waste volumes will be reduced with the development of new and improved chemical processing and waste treatment systems. Currently, major research and development efforts in the waste disposal field are directed toward investigation of several promising solutions to the problem and a program for demonstrating engineering feasibility by pilot plant and field scale testing.

The following approaches are among those being pursued in the AEC's waste disposal development program: (1) the fixation or immobilization of fission products in a solid form,

(2) storage of this solid material in selected geological formations with current emphasis on salt beds, (3) the direct discharge of liquids to selected geologic strata such as salt cavities or deep permeable formations. One of the more promising approaches involves the conversion of high-level wastes to a solid form (preferably chemically inert) with subsequent storage of these solids in salt formations. A prototype 60-gallon per hour (gph) fluidized bed calcination plant for converting aluminum nitrate wastes to a solid oxide form is now under construction at the Idaho Chemical Processing Plant (ICPP). This plant will be in operation during 1961. Future plans call for the adaptation of this plant to treatment of wastes from processing of stainless steel and zirconium-type fuel elements. In addition to the fluidized bed method of reducing wastes to solids, other systems being studied for this purpose include a rotary ball kiln, a radiant-heat spray calciner and a pot calciner. Solutions to the highly radioactive chemical reprocessing waste problem appear feasible from an engineering standpoint, but at least several years of pilot plant and field scale testing will be required to "prove out" proposed systems.

2. As nuclear energy operations continue to expand and facilities become more concentrated, it is likely that in restricted areas, the capacity of the environment (i.e., the atmosphere, hydrosphere, and lithosphere) for safely receiving radioactive effluents will be approached. Accordingly, more efficient methods for the treatment of large-volume low-level waste will be required. Development of treatment processes capable of producing waste effluents of near drinking water quality will probably be needed for low- and intermediate-level liquid wastes. Development work will also be required on increasing treatment efficiencies for the removal of hazardous isotopes, such as strontium and cesium, from laboratory wastes. New concepts for power reactors, involving different types of fuel elements and organic and inorganic coolants and moderators, and also utilizing higher temperatures and pressures, are sure to be developed. To serve them, it will be necessary to develop improved and more efficient handling and disposal systems for a wider variety of contaminated materials.

The utilization of specific geologic formations, which are not accessible to potable water or other natural resources, is being investigated as a possible solution to the highly radioactive reprocessing waste disposal problem. The increasing utilization of the environment for assimilating low- or intermediate-level waste effluents, gives increasing incentive for determining the feasibility of discharging wastes of these categories from various nuclear energy operations into deep permeable formations. Technical problems, such as heat dissipation, corrosion and plugging of the receiving geologic formation, do not appear to be formidable for these wastes because of their lower concentrations and smaller total quantities of radioactive materials and their less complex and restrictive chemical nature.

3. An expanding nuclear industry, with its increasing numbers of power and test reactors, more extensive use of radioisotopes, the advent of industrial chemical processing, etc., intensifies the requirement for specific environmental studies in order to assess quantitatively the impact of these operations on man and his natural resources. Certain techniques, procedures and fundamental principles may be generally applicable in such investigations, but the variability of each site environment makes it essential that local investigation be carried out in order to obtain engineering data which are directly related to the location, design, construction, and operation of specific nuclear facilities. There has been a substantial increase in the number of detailed environmental studies at proposed and operating nuclear facilities. A greater emphasis on this phase of the atomic energy program is visualized during the next

several years. Ecological studies of the behavior of radioactive materials in food chains and biological systems should constitute important parts of this program.

4. Of increasing concern in the nation's waste management program is the growing need for disposal services for solid radioactive wastes from various sources. Such waste materials, with different levels of radioactivity and associated with laboratory and research activities and routine reactor operations, are presently disposed of by land burial at AEC sites and by disposal at sea. Burial ground sites are located in large isolated areas, associated with the major AEC production and testing installations.

AEC licensee operations, which are governed by Federal regulations, can dispose of only nominal quantities of waste materials on site. It has been necessary, therefore, for most licensees to package and transport wastes to off-site disposal locations. Because of the increasing volume of these wastes, there is need in the United States for the establishment of regional, permanent land disposal sites for solid radioactive wastes. The selection of suitable solid waste burial sites should be based primarily on safety, giving proper consideration to economic and convenience factors. The technical feasibility of disposing of these types of wastes by land burial in accordance with acceptable standards for radiation protection has been demonstrated.

Establishment of regional burial ground facilities may be expected to involve complex administrative, legal and public relations issues. Major questions requiring resolution at the present time are (1) the extent to which the Federal or State government will retain long-term responsibility for the disposed material, (2) the role of commercial or industrial participation in the waste disposal field, and (3) actions necessary to provide public acceptance of the establishment of proposed disposal sites. Because of the long-term implications of this problem, it would appear that the long-term responsibility must remain with government, either Federal or State; accordingly, such burial grounds should be established only on publicly owned land.

5. The disposal of solid, packaged wastes into the ocean has been a subject of extensive public interest during the past year. This method of disposal has been used in the U. S. for low-level solid or packaged wastes which emanate from laboratory and normal reactor operations. It is utilized primarily by AEC installations within reasonable shipping distance to coastal ports. The safety of these operations has been supported by (1) the views of experts in the marine sciences and other related fields to whom the problem has been referred, (2) the actual operating experience of the British in disposing of considerably greater quantities of liquid radioactive wastes to the Irish Sea, and (3) the preliminary but direct information from actual field studies made in both Atlantic and Pacific Ocean disposal areas. Further support of the safety of the present sea disposal operations is given in a recently published report of the National Academy of Sciences—National Research Council.[4] A group of marine scientists appointed by the Academy's Committee on Oceanography reported, after conservative evaluation of the various environmental, recreational, and industrial factors involved, that it would be feasible to dispose safely of the types of low-level wastes previously described in several closer-to-shore and shallower depth locations along the Atlantic and Gulf Coast. The Committee further recommended that detailed oceanographic studies be conducted at proposed in-shore sites prior to any utilization for waste disposal purposes. It is noted that the AEC, however, has not made a decision to use or approve the use of in-shore sites.

Radioactive materials discharged to rivers eventually reach the sea in amounts dependent on: the nature of the radionuclides; time of flow; and the physical, chemical, and biological

[4] NAS—NRC Publication 655, *Radioactive Waste Disposal into Atlantic and Gulf Coastal* Waters, 1959.

interactions between the radionuclides and the river environment. The effect of these materials on the ocean environment and ocean resources must be evaluated on the basis of their physical, chemical, and biological behavior in the particular marine environment involved. The return of radioactive materials to man is one of the basic considerations in such an evaluation.

6. It is a general consensus that recovery from highly radioactive fuel reprocessing wastes of specific fission products such as strontium-90, cesium-137, and others, for their beneficial utilization would not appreciably affect the waste disposal problem nor significantly aid in its solution. It is emphasized that *recovery* of specific isotopes is an entirely different problem from that of essentially complete *removal* of all the radionuclides of concern (decontamination factors of the order of 10^8) to facilitate waste disposal. Several processes are being investigated which are theoretically capable of achieving the indicated removal of individual isotopes, but much additional research and development is required before any of these processes could be relied upon to give these removals on a production basis. Recovery of fission products would reduce the problem of heat dissipation in the residual wastes, but would have little influence on the overall safety or cost of waste control. The problem of disposing of the fission product radiation sources after they have served their useful purpose as a radiation device would remain.

7. At one time, sub-micron size particulate contaminants in gaseous effluents presented difficult engineering problems from the standpoint of maintaining concentrations of radioactive materials in air within tolerance limits. Equipment and facilities such as high efficiency filters, deep-bed sand and fiber filters, and iodine and rare gas removal units have been developed for this purpose. As advanced reactor concepts are developed utilizing higher temperatures and various gaseous coolants, new problems involving the handling or processing of large-volume high-activity gases may be expected. Off-gases resulting from the conversion of high-level wastes to an inert, solid form and the removal of certain gases from reactor containment vessels under emergency conditions present problems which may require further development work. Currently, research and development in the treatment of gaseous effluents are directed toward improving efficiencies and capabilities of air cleaning systems with emphasis on the development of filtration equipment for removal of particulates at the high temperatures needed for advanced power and military reactor systems.

In the future, krypton-85 probably will be separated from power reactor fuel reprocessing off-gases because of its potential long-term hazard. These interfering off-gases will require treatment before rare gas removal. This problem has yet to be fully defined but is one not encountered heretofore in fuel reprocessing off-gas treatment.

8. The transportation of highly radioactive materials, including irradiated fuel elements and sealed sources, and the greater distribution of by-product materials around the country have resulted in new technical and administrative problems in the transportation field. The ever-increasing number of shipments of radioactive materials has multiplied the accident hazard potential, including that of accidental releases of radionuclides to the environment. States and municipalities are adopting transportation regulations of their own. In light of continuing developments in the field of radiation safety, existing Federal agency regulations applicable to interstate shipments need review, and probably revision and modification.

The engineering design of shipping containers is based on limited data. To date, the development of container design criteria, based on theoretical and experimental analysis in conjunction with dynamic testing, has not been accomplished. In order to determine container design and fabrication that will optimize both cost and safety factors, a detailed analysis of all significant factors in the transportation problem followed by a field testing program for different types of containers appears desirable.

IV. The Cost of Radioactive Waste Management

THE total investment in waste handling and disposal facilities within the atomic energy program now approximates $200,000,000; about $115,000,000 represents capital investment in underground storage tanks and appurtenances utilized for the long-term retention of high-level radioactive wastes. The estimated annual operating cost of all waste handling operations is approximately $6,000,000. Initial waste disposal costs, though large in absolute values, are a relatively small fraction of unit nuclear power costs. Estimates based on recent studies indicate that the storage of highly radioactive fuel reprocessing wastes in "perpetual care" tanks for several hundred years can be accomplished for an estimated 0.1 to 0.15 mils per kilowatt hour electrical (kwhe) for most reactor fuel types.

Limited data from several power reactors now under construction in the United States show capital costs for waste handling and treatment systems ranging from $1.3 million to over $4 million. Such costs range from $10 to $30 per electrical kilowatt or approximately 3–5% of the total plant cost. As more operating data and experience are obtained, it would seem likely that these costs can be reduced. In any case, the cost of effluent control does not loom as a barrier to achieving economic or competitive nuclear power. If economic power from nuclear fission is not achieved, it will not be due to waste management costs. It is generally accepted that to an extent consistent with safety, the diluting power of the environment may be used in disposal of low-level wastes. It has been demonstrated that present dispersal methods result in radioactivity concentrations well below established permissible limits. The cost of "absolute processing" or containing large volumes of low-level wastes would be prohibitive and could present an unreasonable economic burden on the industry.

V. Magnitude of Future Waste Management Problem

The growth of nuclear power in the United States has been estimated by numerous authorities in the field. It is generally conceded that in the next 20 years the principal source of fission products will be from power reactor operations.

In a future nuclear power economy, the volumes of power reactor wastes to be handled must be considered in relation to the cumulative quantity of radioactivity being generated by other atomic energy operations. At the present time, the waste volumes and activities from stationary power reactors obviously are small when compared with those of government production and test reactors. It appears reasonable to expect that by 1965 there will be in the range of 10,000 to 20,000 thermal megawatts of power reactor capacity in the U. S., and that by 1980 this figure will grow to about 100,000 thermal megawatts or more. The total fission product inventory resulting from the processing of spent power reactor fuels in 1980 has been estimated at 10 billion curies. About 800,000,000 curies will be strontium-90.

It is estimated that approximately 36,000,000 gallons of different types of high-level fuel reprocessing wastes will be accumulated from the reprocessing of power reactor fuels in the United States by the year 1980. By comparison, a total of 65,000,000 gallons of this category of wastes has accumulated since the beginning of the atomic energy program. It appears, therefore, that within the next 20 years the wastes produced by the power industry will be considerably less than the volume which is presently in storage at Hanford (about 50,000,000 gallons). It should be noted that the above estimates are directly dependent on estimates of growth of nuclear power, reactor fuel types, and fuel reprocessing technology.

VI. Federal-State Relationships

In the nuclear energy industry, some waste management policies must be different from those of other manufacturing industries. This is because of the unique characteristics of radioactive wastes referred to previously. The long effective life of some of the materials makes it mandatory that agencies of government retain the long-term responsibility or custodial role for the material in order to assure continued protection of the public health and safety. Eventually this role may be assumed by State governments, but it is more likely this responsibility will be distributed at several levels of government and between various agencies of government. In recent Congressional legislation pertaining to amendments to the Atomic Energy Act of 1954, the responsibility for waste disposal was continued by the Federal government within the Atomic Energy Commission. Procedures were established, however, whereby transfer of responsibility to the states could be made for the control of some other classes of radioactive materials.

Close technical working relationships with many state agencies with responsibilities in the fields of waste disposal and water pollution control have been maintained by the AEC. These federal-state relationships have been maintained without question of the jurisdiction of Federal and State agencies. As State governments develop competencies in this field, administrative control over waste management, especially dealing with low-level wastes and waste dispersal operations, might well be assumed by these agencies.

VII. International Aspects

International aspects of the waste disposal problem are important, particularly in connection with ocean disposal and operation of nuclear propelled vessels and aircraft. Of specific interest to international programs are technological data developed on the subjects of land burial and sea disposal of solid waste materials and environmental investigations involving the dispersal of low-level waste effluents. Waste disposal problems transcend political boundaries. The disposal of gaseous and liquid waste effluents to the atmosphere and surface waterways may be severely limited in densely populated countries with comparatively small land areas and intensively utilized natural resources.

The potential hazards associated with the use of mobile reactors, such as submarines, merchant ships, and aircraft, is becoming of increasing concern. The discharge of normal reactor wastes from these facilities and the possibility of releasing substantial quantities of radioactivity within harbors in the event of accidents are problem areas now under active investigation.

VIII. Effects of Waste Management Operations on Man's Over-All Radiation Exposure

Man is exposed to radiation from several man-made sources: (1) medical and industrial use of X-ray machines, (2) industrial applications of radioactive materials and atomic energy, (3) radioactive fallout from weapons tests, (4) radioactive waste materials, as well as naturally occurring radionuclides. From available evidence, medical exposures from X-rays constitute the major source of radiation to man. At the present time the contribution from radioactive wastes is substantially less than that from world-wide fallout.

From an environmental health and safety standpoint, the types of potential waste management problems that will require continued surveillance and supervision in the future in order to minimize exposure of man and his natural resources are as follows: (1) control and careful supervision of releases of low-level wastes in order to assure adequate protection of the environment, (2) possible leaching or relocation of small fractions of high-level wastes from underground storage sites, and (3) accidental irregular releases from nuclear energy operations. Since effluent control technology for low-level wastes is relatively straightforward, the contribution of radiation exposure from waste dispersal operations should continue to be a small percentage of the total exposure of man from all radiation sources. Continuous surveillance and monitoring is required, however, to control build-up of contaminants in individual links of the food chain from particular environmental concentration factors that might prevail.

There does not appear to be anything inherent in the over-all waste control problem that need retard the development of the nuclear energy industry, at the same time assuring adequate protection of the public health and safety.

Abel Wolman, *Chairman*
J. A. Lieberman
F. L. Culler, Jr.
A. E. Gorman
L. P. Hatch
H. H. Hess
C. W. Klassen
Sidney Krasik
H. M. Parker
Walter A. Patrick
Sheppard T. Powell
Leslie Silverman
Philip Sporn
Conrad P. Straub
C. V. Theis
F. Western

Report of the

COMMITTEE ON OCEANOGRAPHY AND FISHERIES

REPORT OF THE
COMMITTEE ON OCEANOGRAPHY AND FISHERIES

I. Introduction

In its 1957 report(1)*, this Committee made several policy recommendations concerning the introduction of radioactive material into the oceans. We pointed out that until more knowledge of physical and biological processes had been obtained, it was necessary to err on the side of safety, that is, to introduce much smaller quantities of radioactive substances than the sea might be capable of receiving in order to insure that no damage would be done to marine resources. A research program to obtain the necessary information was recommended together with regulation and monitoring at both national and international levels and a greater effort to spread understanding of the problems involved among scientists and laymen.

Since the 1957 report was published, much has occurred to sharpen the issues involved and to increase our understanding. The Committee itself, acting either as a subcommittee of the Academy's Committee on Oceanography or in cooperation with them, has published three reports: one on the disposal of low-level wastes off the Atlantic and Gulf coasts of the United States(2), another on wastes from nuclear-powered ships(3), and a third giving more specific recommendations about research and monitoring than were possible in 1956(4). Summaries of these three papers are given in the present report. A fourth report, on the disposal of radioactive wastes off the west coast of the United States is in preparation. In all of these, an attempt has been made to make quantitative recommendations and calculations showing the maximum amounts of various radioisotopes that can safely be disposed of in sea water of different areas.

Additional national emphasis has been placed on the development of oceanography in general and on important applied problems such as the disposal of radioactive wastes into the oceans. In October 1958, the Chief of Naval Research released the results of a study under the title *Project Tenoc*, which outlined the existing research programs, facilities, and fundings in United States oceanographic organizations, and gave an estimate of the additional effort required by each organization to provide for the needs of the Navy during the next ten years.

Chapters of the report of the Academy–Research Council's Committee on Oceanography, *Oceanography, 1960 to 1970*, were issued in 1959, and the entire report will be published in the near future. Many of its general and detailed recommendations for an expanded national and international program of oceanographic research and surveys are beginning to be implemented through the Federal Council of Science and Technology, and the Congress. Included in these recommendations was an increase in the next five years of research effort on problems related to artificial radioactivity in the oceans from the present level of about 2 million dollars per year to an annual level of 6 million dollars.

During January, February, and July, 1959, the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy of the Congress of the United States held hearings on

* Numbers in parenthesis indicate references in section IV of this report.

Industrial Radioactive Waste Disposal. The record of these hearings appears in five volumes of 3142 pages, much of which is concerned with disposal to the oceans.

In September 1959, Senator Magnuson of the State of Washington and other members of the Subcommittee on Merchant Marine and Fisheries of the Senate Committee on Interstate and Foreign Commerce introduced a bill (S. 2692, 86th Congress, 1st Session) which, if enacted, would authorize an increase in Federal support of oceanography along the lines recommended in the Academy's report: "To advance the marine sciences, to establish a comprehensive ten-year program of oceanographic research and surveys; . . . to assure systematic studies of effects of radioactive materials in marine environments; to enhance the general welfare; and for other purposes."

A companion bill (H. R. 9361, 86th Congress, 2nd Session) was introduced in the House of Representatives by Congressman Pelly of Washington.

Considerable experience has been gained concerning disposal of relatively large quantities of low-level wastes in the Irish Sea off the British Windscale atomic power plant and in the Columbia River near the Hanford Works of the U. S. Atomic Energy Commission. The results, which are summarized in this report, give a valuable confirmation of the computations in the reports on low-level waste disposal and wastes from nuclear-powered ships. It seems evident that with careful control and monitoring, rather large quantities of radioactive wastes, possibly several thousand curies a month of certain isotopes, can be disposed of safely in some coastal waters or in large rivers.

When our first report was written, fallout from weapons tests was the principal source of artificial radioactive materials in the sea. Although this is probably still true of the oceans as a whole, radioactivity from the peaceful uses of atomic energy will probably overshadow the amount from fallout in the future. Even at the present time, these sources predominate in certain areas.

The radioactive pollutants with which we are concerned may come from the following sources:

A. *Nuclear power plants (on land or at sea)*

1. Low-level liquid wastes due to induced activity in cooling water, or due to leakage of fission products from damaged fuel elements to cooling water.
2. Accidents to the reactor system.
3. Designed disposal of radioactive materials, either packaged or not.

B. *Laboratories, hospitals, industrial plants, and military installations.*

1. Packaged, low-level wastes and contaminated refuse.
2. Discharge of low-level waste solutions either directly or indirectly into the sea.

C. *Experiments—large scale experiments in physical, chemical, and biological oceanography.*

D. *Atomic explosions—release of relatively large quantities of radioactive materials.*

1. Experimental—weapons tests.
2. Peaceful uses—harbor construction.
3. Warfare.

An example of the possible peaceful uses of atomic explosions is *Project Chariot* of the U. S. Atomic Energy Commission. This is an experiment to determine the factors involved in the use of nuclear explosives to excavate an area that could be used as a harbor. The project site is at the mouth of the Ogotoruk Creek between Cape Thompson and Cape Seppings on the northwest Alaska coast. An extensive survey program is being carried out by the Commission with the cooperation of university research laboratories and U. S. Government agencies, among other purposes to make a biological inventory of plant, animal, and bird life of the sea, land, and fresh water in the site vicinity; to identify the food chains and other ecological features of the regions; and to study human geography and habit.

Progress has been made in studying the circulation and mixing of the sub-surface waters of the ocean through measurements of the distribution of radium, carbon-14, ionium and thorium, and lead isotope ratios, and through direct current measurements. Much of this work was done as part of the program of international scientific collaboration of the International Geophysical Year, and machinery has been established through the special Committee on Oceanic Research of the International Council of Scientific Unions, to continue and expand this collaboration.

In the past, much thought has been given to the possible uses of tracer experiments using large amounts of artificial radioactive materials to study the motions of the sub-surface waters. Recent experiments with fluorescent dyes indicate that these materials, which are cheaper, safer, and much more easily handled than radioactive isotopes, could be used very effectively in such experiments. With present techniques, dye concentrations of two parts in a thousand billion can be detected, corresponding to two kilograms of dye per cubic kilometer of water.

At the Geneva Conference on the Law of the Sea in 1958, a Convention on the High Seas was adopted. Among its provisions are:

> "1. Every State shall take measures to prevent pollution of the seas from dumping of radioactive waste, taking into account any standards and regulations which may be formulated by the competent international organizations.
>
> "2. All States shall cooperate with the competent international organizations in taking measures for the prevention of pollution of the seas or air space above, resulting from any activities with radioactive materials or other harmful agents."

The Conference also adopted a resolution to the effect that the International Atomic Energy Agency should undertake to coordinate research on which could be based standards and regulations for the prevention of pollution of the high seas by radioactive materials.

In response to these, the International Atomic Energy Agency has established a continuing panel of experts on sea disposal of radioactive wastes. Recently, the Agency, in cooperation with the United Nations Educational, Scientific, and Cultural Organization, sponsored an international conference at Monaco on disposal of radioactive wastes in the sea and in geological structures.

It was evident at this conference that many oceanographers and marine biologists of European countries and the USSR, as well as members of the general public in those countries, are strongly opposed to the introduction of any artificial radioactive materials into the oceans or their bordering seas. On the other hand, many countries, such as Netherlands, Sweden, Italy, and Japan, are planning atomic power installations on or near the sea coast and some of the radioactive materials produced by these plants will inevitably find their way, either by design or accident, into the sea. The same result will come from the development of nuclear-powered merchant ships and naval vessels, particularly of submarines, which have very little excess capacity to store radioactive waste liquids.

We have here what is in some respects a typical example of the conflicting use of marine resources. This Committee is convinced that the conflict could be largely resolved by an adequate program of research and education. More information is certainly needed on the uptake, accumulation, retention, and transfer of radioactive materials by marine organisms in the food chains leading to man, and on the effects of atomic radiation on the ecology of oceanic plants and animals. The information presently available on these matters and that to be obtained through research should be more widely disseminated, both to allay the fears of biologists and the public, and to emphasize to the engineers the need for great care in disposing of radioactive materials in the marine environment.

II. Conclusions and Recommendations

General Policy

Limited quantities of artificial radioactive materials can safely be introduced into the ocean for scientific and engineering purposes if the tests are planned with the environment in mind. Disposal of limited quantities of low-level waste can be carried out under proper safeguards of supervision and monitoring.

It is too soon to decide whether any high-level wastes can or should be disposed of at sea. Additional research on sea and land disposal should answer this question. With the development of the atomic power industry, very large quantities of high-level wastes will be produced in coming decades, and it may prove both safe and economically desirable for some of these materials to be finally disposed of in the ocean.

There must be sufficient monitoring of disposal sites to ensure public health and safety, and to protect marine resources. Such monitoring should not be performed solely by the regulating agency. Records of the quantity and type of radioactive wastes and the areas in which they are disposed of should be maintained in a national center. These records should be available to interested groups, and periodic summaries should be issued. The records should be disseminated abroad through the International Atomic Energy Agency in order to spur international understanding and agreements.

Availability of Information

An increasing concern about the introduction of radioactive wastes into the sea is apparent at all levels, from local communities to international organizations. This is a natural consequence of the expanded use of nuclear energy and the consequent increase in the amounts of waste materials to be disposed of. Fortunately, new information on the characteristics of the ocean, and experience gained from the release of radioactive materials, is providing a background for the formulation of acceptable policies for radioactive materials in the marine environment. The problems involved are complex and can be solved only through the joint efforts of all agencies: local, national, and international. The future will bring new and unanticipated problems, and differing interpretations of incomplete information may lead to controversy. Joint efforts to meet present problems and to resolve possible future differences will depend upon available knowledge and its interpretation. A full and free exchange of basic information is necessary. To supplement exchange of information through reports, publications, and scientific conferences, consideration should be given to the establishment of data centers where records of disposal operations, monitoring studies, and similar systematic data may be maintained.

Education

It is important that available facts, objectives, and areas of disagreement on disposal of radioactive materials in the oceans be made available to the public, to scientists, and to government administrators and statesmen. While some of the problems are disturbing and difficult, all are subject to rational attack based on measurement and analysis. Education in these matters must be aimed at individuals, states, and nations.

Permissible Concentrations of Radionuclides in Sea Water, and Regulations for Different Types of Disposal

In the absence of direct monitoring information for a specific area, the permissible concentrations in sea water for different radioisotopes must be estimated. Conservative estimates can be made from the allowable total body burdens and the maximum permissible concentrations in drinking water, assuming that all the artificial radiation received by the body comes from marine foods and provided that the degrees of concentration of isotopes by marine organisms and the amounts of the stable isotopes in the body and in the sea water are known. In many cases the permissible sea water concentrations could be increased if the pathways of accumulation by fishes and edible invertebrates, and the biological half-lives in marine organisms were better understood. Several sources of radioactive contamination of marine products will exist (for example, wastes from nuclear-powered ships, and from shore-based atomic power plants), and decisions must be made concerning the fraction of the total concentration that can be allocated to each source. Moreover, artificial radioactivity can reach the body from the air and from food and drinking water originating on land, as well as from sea food. Consequently, the fractions of the total radiation that can come from sea food must be determined. Such determinations should be made by legally constituted regulatory agencies, guided by the general recommendations of the National Committee on Radiation Protection and Measurements, and by the special circumstances peculiar to each area. It may be necessary to formulate different sets of recommendations for the general population and for communities and individuals that depend heavily on aquatic plants and animals for their food. Ultimately, specific regulations may be required to cover each type of situation involving introduction of radioactive materials in the environment.

Basic and Applied Research

Our understanding of the marine environment is presently inadequate to provide more than crude and restrictive answers to questions concerning the consequences of introducing radioactive materials. Greater research efforts are needed, both at sea and in the laboratory. At sea, studies should be made of estuarine and coastal environments, of circulation and mixing in the deep ocean, and of the physical and biological processes by which materials introduced into deep water may be transferred to the surface layers or removed by sedimentation. The biological half-lives of radioisotopes in marine organisms, the pathways of accumulation through the food chain, and sedimentary exchange processes need to be studied, both in the laboratory and at sea. It is obvious that these studies are of more than local or national concern, and especially those concerned with the open ocean should be undertaken jointly by all maritime nations.

Tracer experiments should be made to evaluate the effects of currents and turbulent mixing. For experimental purposes, dyes can be employed for certain of these studies, but opportunities to use radioactive tracers should be exploited as opportunities arise.

Seagoing equipment and techniques for conducting radiological research and monitoring need to be improved and at least partially standardized. Many devices exist in research form, but it is essential that these fundamental tools be made reliable enough so that the scientists can concenrate on measurements and on interpretations of data rather than on equipment.

III. Summary of Recent Developments

1. *Recommendations Concerning the Disposal of Packaged Low-Level Wastes along the Atlantic, Gulf, and Pacific Coasts.*

In January 1958, the Bureau of Commercial Fisheries, the U. S. Atomic Energy Commission, and the Office of Naval Research requested the Committee on Oceanography of the National Academy of Sciences—National Research Council to conduct a detailed study of the problems of the disposal of low-level radioactive wastes into the Atlantic and Gulf of Mexico coastal waters of the United States. Later a similar request was made for the waters off the Pacific coast of North America. The Committee on Oceanography in turn requested the Committee on Biological Effects of Atomic Radiation on Oceanography and Fisheries to appoint two working groups to undertake these tasks. The report of the East Coast working group was issued in 1959(2).

Of special concern was the use of near-shore regions as disposal areas for the low-level radioactive wastes generated in university and industrial laboratories, hospitals, and research institutions licensed by the AEC to use relatively small quantities of radioactive materials, and the disposal of such materials in packaged form. Consideration was given to the probable fate of materials introduced in this way, the role of currents and mixing in dispersing the material, and the hazards to health that might arise from their reconcentration in marine organisms used as food. Using the best estimates available for each of these dispersing and concentrating mechanisms and taking in each case the most conservative value, a maximum rate of disposal of 250 curies of soluble Sr^{90} per year or its equivalent in terms of maximum permissible concentrations in sea water was recommended. This rate is probably one hundred and possibly one thousand times below the rate that would return the waste to man at maximum permissible levels, the latter based upon the recommendations of the National Committee on Radiation Protection and Measurements(5).

Several locations were suggested along the Atlantic and Gulf Coasts which appeared on the basis of incomplete data to be capable of receiving the 250 curies of Sr^{90} per year or its equivalent. It was recommended that, prior to the start of disposal operations in any one of these locations, a detailed survey be made to determine whether or not the rates of dispersal and concentration used in arriving at the 250-curie rate of disposal are applicable, and also to provide a pre-use picture of conditions upon which the effects of disposal could be determined.

Because of marked differences in environmental conditions between the Pacific and Atlantic coasts, the West Coast working group felt it necessary to reevaluate many of the processes affecting the dispersal and concentration of radioactive materials introduced into the sea. Their report will include recommendations concerning various types of source materials and will indicate the amounts that can be introduced at various distances from the coast and in various depths of water. It is expected that this report will be issued by the Academy–Research Council in 1960.

2. *Recommendations Concerning the Disposal of Wastes from Nuclear-Powered Vessels.*

In June 1958, the U. S. Atomic Energy Commission requested the Committee on Oceanography of the National Academy of Sciences—National Research Council to consider the problem of disposal of radioactive wastes from nuclear-powered ships into the marine environment, and to present recommendations that might aid in developing design criteria and operating doctrine relative to waste disposal from such vessels. This request was referred to the Committee on the Biological Effects of Atomic Radiation on Oceanography and Fisheries, which appointed a special working group. The report of the working group was issued in 1959(3).

This report was an evaluation of:

1. The nature and amount of radioactive waste materials that could conceivably be introduced into the sea through normal operations of nuclear-powered ships.
2. The routes by which such introduced activity would return to man from the sea.
3. The portion of the maximum permissible dose to man, allotted to the peaceful uses of nuclear energy, that should be permitted to originate from waste disposal operations from nuclear-powered ships.
4. The concentration by marine organisms of the various significant isotopes in the wastes.
5. The processes of dispersion of the wastes within the various subdivisions of the marine environment.
6. The permissible rate of introduction of radioactive waste materials into the various subdivisions of the marine environment.

The report dealt specifically with the wastes which would originate from a water-cooled reactor.

The following subdivisions of the marine environment considered, and the permissible seafood concentrations recommended were:

1. Harbors, estuaries, and coastal waters out to two miles from the shoreline: permissible concentrations in seafood of radioisotopes from nuclear-powered ships shall not exceed those for drinking water.
2. The coastal area, between 2 miles and 12 miles from the coastline: permissible concentrations in seafood of radioisotopes from nuclear-powered ships shall not exceed those for drinking water.
3. The outer continental shelf, extending from 12 miles offshore outward to the 200-fathom depth contour, in known fishing areas: permissible concentrations in seafood of radioisotopes from nuclear-powered ships shall not exceed twice the values for drinking water.
4. On the outer continental shelf, outside of known fishery areas: permissible seafood

concentrations originating from nuclear-powered ships may be ten times those for drinking water.

5. The open sea, considered to comprise those ocean areas more than 12 miles from shore having depths greater than 200 fathoms: permissible seafood concentrations from nuclear-powered ships may be five times those for drinking water for known fishing areas, and twenty-five times outside of fishing areas.

Based on these maximum permissible concentrations in seafood, specific and detailed recommendations were made concerning the types and amounts of waste that can safely be introduced into the various types of marine environments.

3. *Suggested Methods of Calculation of the Permissible Concentrations of Radioactive Isotopes in Sea Water.*

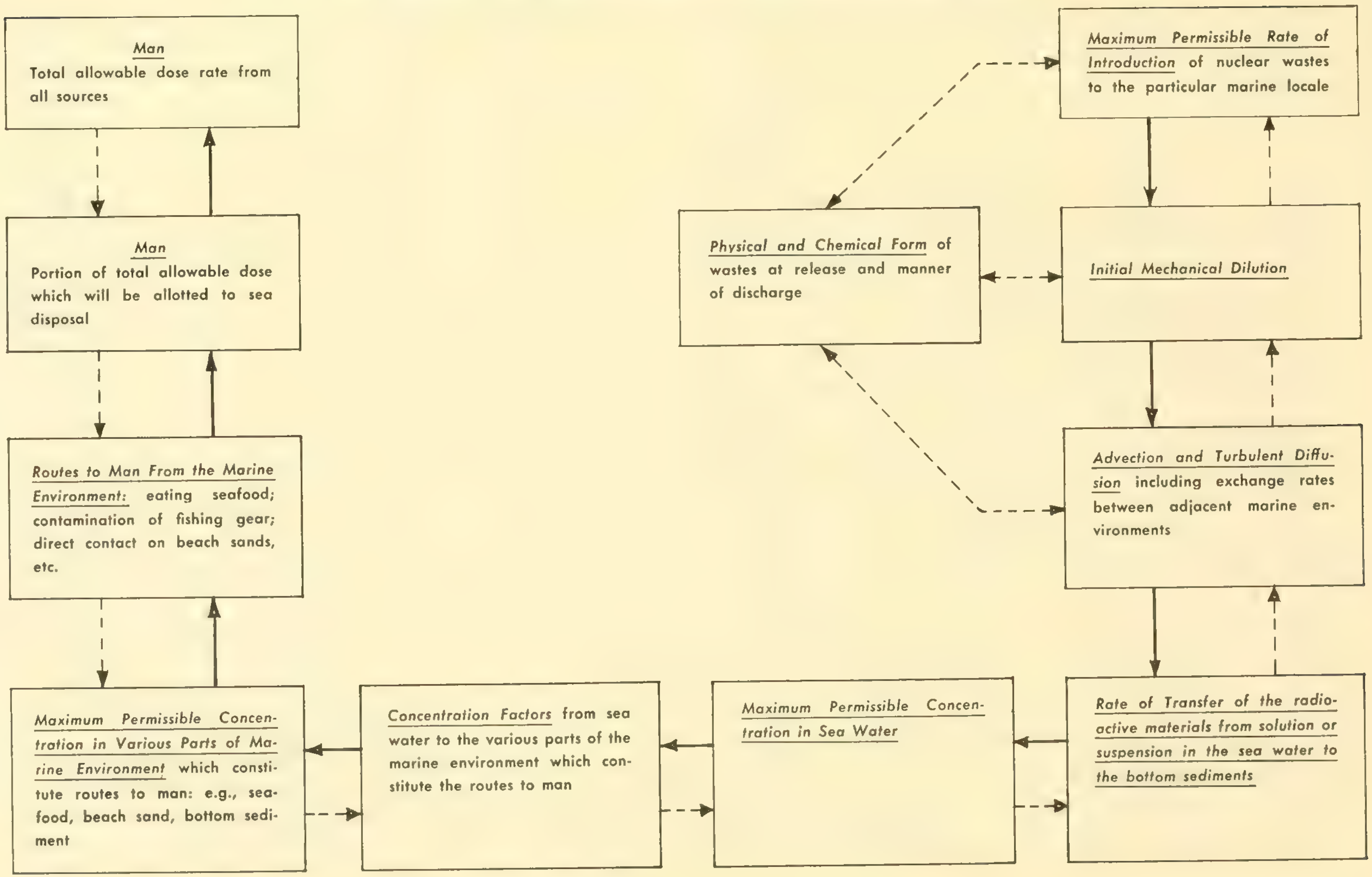
The fate of radioactive materials introduced into the marine environment depends on five things: the physical and chemical form of the material; initial mechanical dilution in the receiving waters; advection and turbulent diffusion; uptake by suspended silt and bottom sediments; and concentration by organisms. Evaluation of the quantity of radioactive materials that can be introduced into any particular marine locality involves a step-by-step consideration of all these factors, especially as they affect the possible return of the radioactive material to man. Figure 1, taken from NAS–NRC Publication 658(3), presents in schematic form such a step-by-step procedure. The solid arrows between blocks in the diagram indicate the route taken by the radioactive material in returning to man, while the dashed arrows indicate the reverse course taken in the evaluation. The evaluation depends on the maximum permissible rate of exposure of different body organs to radiation. These permissible rates of exposure are published and revised from time to time by the national and international committees on radiation protection.

Radioactive isotopes in the sea may affect man principally through his use of marine plants and animals as food. Consequently, the quantities of radioactive materials that can safely be introduced into the marine environment can be most directly controlled from the results of monitoring the radioactivity in edible marine organisms. (It is also necessary to consider the rate at which human beings consume marine foods and the fraction of the total radiation exposure that can safely be assigned to marine sources.) Adequate monitoring is costly and difficult, however, and must of necessity lag behind the first stages of the disposal program. In planning for marine disposal and in choosing between different disposal sites and methods, it is thus essential to be able to make as realistic estimates as possible of the maximum permissible concentrations of various radioactive isotopes in sea water. It should be emphasized that this is only one step in the solution of the problem and the calculated permissible concentrations in sea water are not to be regarded in the same way as the published permissible concentrations in drinking water. In the present state of knowledge, the permissible concentrations in sea water can be regarded only as interim values; moreover, they should be thought of as average values for the relatively large volumes of water from which edible marine animals and plants extract their body materials.

In making estimates of permissible concentrations in sea water, account must be taken of the fact that sea water is a solution of almost all the elements; that the concentrations of many elements are known and are constant within more or less well-defined limits; and that marine plants and animals concentrate, often by very large factors, both radioactive and non-radioactive isotopes.

FIGURE 1

Schematic Presentation of the Step-by-Step Considerations which Should be made in Evaluating the Suitability of Any Marine Locale as a Receiver of Nuclear Wastes



Hazards to human beings from a radioactive nuclide in seafood will result from radiation in the gastro-intestinal tract as the food passes through the body, and from radiation in other body organs which accumulate the radionuclide. As shown in National Bureau of Standards Handbook 69(5), the maximum permissible concentrations in drinking water for many isotopes, including Cr^{51}, Fe^{59}, Co^{60}, Zr^{95}, Nb^{95}, Ru^{106}, Ce^{144}, and Ta^{182}, are limited by the radiation exposure of the gastro-intestinal tract; for others, including P^{32}, S^{35}, Ca^{45}, Fe^{55}, Zn^{65}, Sr^{90}, I^{131}, and Cs^{137}, the accumulated burden in body organs is limiting.

For the first group of isotopes, the concentration per unit volume of marine food must be held below a certain value; for the second group, the specific activity (that is, the ratio of the radioactive to the non-radioactive species in the seafood) must be controlled.

Organisms do not, in general, distinguish significantly between the radioactive and the non-radioactive isotopes of a particular element. Hence, if the total uptake of any element by a human body organ comes from eating seafood, the specific activity in the body cannot, in general, exceed the specific activity in the ocean. (Exceptions may possibly occur if the radioactive and the non-radioactive species are in different chemical states in sea water.) Indeed, the specific activity of the radioactive isotope accumulating in the body will be much less than in the ocean if the isotope has a short radioactive half-life, because the concentration in marine food organisms and in body organs will be reduced by radioactive decay. Consequently, whenever the gastro-intestinal tract is not the critical body organ, the permissible specific activity of a radioisotope in sea water will be greater than the permissible specific activity in the body, often by a large factor for isotopes with a short radioactive half-life. (Obviously, this will also be true when the concentration in sea water of the stable species of the element is very small. In these cases, the ratio of the radionuclide to a non-isotopic carrier used by the body must be considered.)

These qualitative statements can be put in quantitative terms through the following calculations:

Case I—Critical body organ not the gastro-intestinal tract.

Let I_r and I_n be respectively the radioactive and non-radioactive isotopes of a particular element.

I_{rb} and I_{re} are the maximum permissible concentrations of I_r in the critical human body organ and in sea water, and I_{rf} is the concentration of I_r in marine food organisms. Values of I_{rb} for the total body, corresponding to the concentration in the critical organ for different radioactive isotopes, can be computed from Table 1 of NBS Handbook 69, referred to above.

I_{nb}, I_{nf}, and I_{ne} are respectively the concentrations of I_n in the critical body organ, in marine organisms, and in sea water.

K is the radioactive decay constant of I_r.

B and B_f are the corresponding constants for the biological elimination of I_r and I_n from the body and from marine organisms.

$$K = \frac{0.69}{T_{p\frac{1}{2}}} \quad (T_{p\frac{1}{2}} = \text{radioactive half-life of } I_r)$$

$$B = \frac{0.69}{T_{b\frac{1}{2}}} \quad (T_{b\frac{1}{2}} = \text{biological half-life of } I_r \text{ and } I_n \text{ in the human body. Preliminary values of } T_{b\frac{1}{2}} \text{ are given in National Bureau of Standards Handbook 52(6).}$$

$$B_f = \frac{0.69}{T_{bf\frac{1}{2}}} \quad (T_{bf\frac{1}{2}} = \text{biological half-life of } I_r \text{ and } I_n \text{ in marine organisms})$$

F is the factor of concentration of I_r and I_n in marine organisms compared with sea water.

C_r and C_n are the rates of uptake of I_r and I_n by the critical body organ.

$$C_r = a\, I_{rf}\, M \tag{1a}$$

$$C_n = a\, I_{nf}\, M \tag{1b}$$

where a is the fraction of the ingested isotope taken up by the body organ, and M is the weight of marine organisms eaten per unit time. Moreover,

$$\frac{dI_{rb}}{dt} = C_r - (K+B) \cdot I_{rb}$$

$$\frac{dI_{nb}}{dt} = C_n - B\, I_{nb}$$

When the rates of uptake C_r and C_n are constant, the solutions are

$$I_{rb} = \frac{C_r}{K+B}\left(1 - e^{-(K+B)t}\right) + I_{rbo}\, e^{-(K+B)t} \tag{2a}$$

$$I_{nb} = \frac{C_n}{B}\left(1 - e^{-Bt}\right) + I_{nbo}\, e^{-Bt} \tag{2b}$$

where I_{rbo} and I_{nbo} are the initial body concentrations of I_r and I_n when $t=0$.

The amounts of I_r and I_n in the body increase with increasing time toward an equilibrium value, when t is long compared to $T_p\frac{1}{2}$ and $T_b\frac{1}{2}$, given by

$$I_{rb} = \frac{C_r}{K+B} \tag{3a}$$

$$I_{nb} = \frac{C_n}{B} \tag{3b}$$

Dividing (3a) by (3b) we see that at equilibrium the specific activity in the critical body organ of the radioactive isotope with respect to the non-radioactive species is

$$\frac{I_{rb}}{I_{nb}} = \frac{C_r}{C_n}\left(\frac{B}{K+B}\right)$$

Substituting for C_r and C_n from (1a) and (1b)

$$\frac{I_{rb}}{I_{nb}} = \frac{I_{rf}}{I_{nf}}\left(\frac{B}{K+B}\right)$$

It can be shown in a similar fashion that when marine food organisms accumulate an element directly from sea water

$$\frac{I_{rf}}{I_{nf}} = \frac{I_{re}}{I_{ne}}\left(\frac{B_f}{K+B_f}\right) \tag{4}$$

and therefore

$$\frac{I_{rb}}{I_{nb}} = \frac{I_{re}}{I_{ne}}\left(\frac{BB_f}{K^2+KB_f+KB+BB_f}\right)$$

Solving for I_{re}

$$I_{re} = \frac{I_{rb}}{I_{nb}}\, I_{ne}\left(1 + \frac{K^2+KB_f+KB}{BB_f}\right) \tag{5}$$

For most elements, eq. (4) and consequently eq. (5) are much oversimplified, because accumulation by food fishes and edible marine invertebrates does not take place directly from sea water but through a complex food chain, starting with marine plants. Where there are n links in the food chain, we may write.

$$I_{re}=\frac{I_{rb}}{I_{nb}}I_{ne}\left(1+\frac{K^{n+1}+K^{n}\Sigma B_{i}+K^{n-1}\Sigma B_{i}\,B_{i-m}+\;.\;.\;.}{\Pi B_{i}}\right)$$

However, so little is known about the biological half lives in different marine organisms and the mode of accumulation of minor and trace elements that this complexity is not warranted at the present time.

In the absence of adequate knowledge, it is conservative to assume that B_f is greater than either B or K; in other words, that the hold-up time in marine organisms is short. Consequently, for those elements of long radioactive half life where $K \ll B < B_f$, eq. (5) approaches.

$$I_{re} \approx \frac{I_{rb}}{I_{nb}} I_{ne} \tag{5a}$$

That is, *the permissible specific activity in the oceans is about equal to that in the critical body organs for isotopes of long radioactive half-life.*

When $B_f > K \gg B$

$$I_{re} \approx \frac{I_{rb}}{I_{nb}} I_{ne}\left(1+\frac{K}{B}\right) \tag{5b}$$

That is, *for isotopes of short radioactive half-life and long biological half life in the human body, the permissible specific activity in the ocean is much greater than in the body.* Examples are P^{32} and I^{131}, which have biological half-lives in the human body 20 to 100 times greater than the radioactive half-life. (If the biological half-life in marine food organisms is also known, the permissible activity in the sea water will be further greately increased.)

So far, we have discussed only adult organisms for which the rates of uptake of different substances are roughly constant. For a rapidly growing organism, we must return to equations of the form of (2a) and (2b). If the growth rate is exponential, as in the early stages of the human fetus, the equation for I_{re} may very well be

$$I_{re}=\frac{I_{rb}}{I_{nb}}I_{ne}\left(1+\frac{K}{G+B}\right)\frac{1-e^{-(G+B)}{}_{t}}{1-e^{-(G+K+B)}{}_{t}} \tag{5c}$$

where $G=\frac{0.69}{T_g}$ (T_g=the doubling time for exponential growth). Comparison of eq. (5b) and (5c) shows that, for rapidly growing organisms, the effect will be to reduce the concentration below that allowable for adults.

The above considerations apply when the gastro-intestinal tract is not the critical organ. They rest on the assumption that the amounts of non-radioactive isotopes of the radioactive species in the critical body organs are not markedly different for persons on a seafood diet than for the rest of the population, and that the radioactive and the non-radioactive isotopes have a similar biological behavior.

Case II—Critical body organ is gastro-intestinal tract.

When the gastro-intestinal tract is the critical body organ, we are no longer concerned with specific activity, but only with the concentration per unit volume of the radioactive isotope in the food. Returning to eq. (4), we see that

$$I_{re}=I_{rf}\frac{I_{ne}}{I_{nf}}\left(\frac{K+B_f}{B_f}\right)=\frac{I_{rf}}{F}\left(1+\frac{K}{B_f}\right)$$

I_{rf} is the amount of the radioisotope per unit volume of seafood, and hence is comparable to the $(MPC)_w$ values for the gastro-intestinal tract given in Handbook 69. In this publication, it is assumed that a human being drinks 15 liters of water per week. This is about 10 times the amount of seafood eaten, even for those human beings who obtain all their protein from seafood. Hence the radioactivity per unit volume in the intestinal tract can be diluted by a factor of 10. We conclude that

$$I_{re}\geqq 10\frac{(MPC)_w}{F}\left(1+\frac{K}{B_f}\right) \tag{6}$$

For isotopes in which the radioactive half-life is much longer than the biological half-life in marine organisms, eq. (6) reduces to

$$I_{re}\approx 10\frac{(MPC)_w}{F} \tag{6a}$$

In two previous reports of this Committee(2, 3), eq. (6a) was used in all cases to compute I_{re}, the permissible concentration of radioactive isotopes in sea water. Following the recommendations of the National Committee on Radiation Protection and Measurements, one-tenth of the MPC values in drinking water given in Table 1 of Handbook 69 for the critical body organ were employed in the calculations. These are the recommended values for the general public outside of areas of occupational exposure. As has been stated above, this procedure is clearly applicable for long-lived elements in which the gastro-intestinal tract is the critical organ. It errs on the side of safety for short-lived elements in which the gastro-intestinal tract is critical, and may give either too large or too small values when accumulation of radioisotopes in other organs is critical.

A more correct procedure in all cases is to compute I_{re} from both eq. (6a) and (5b), introducing in (6a) one-tenth of the MPC values for the gastro-intestinal tract given in Handbook 69 and in (5b) one-tenth of the specific activity permissible for the critical body organ. (This is equal to the permissible total body burden for the critical organ given in Handbook 69 divided by the total amount of the non-radioactive isotope in the body. Most values for the latter are given in Handbook 52). The permissible concentration in sea water is then the smaller of these two values. Table 1 illustrates the computations. The tentatively accepted values are underlined. At least for adults, these are undoubtedly quite conservative for elements with relatively long effective biological half-lives in the marine food chain (see pages 79, 80).

Comparisons of the permissible sea water concentrations calculated by the above method with those previously published by this Committee, and with the maximum permissible concentrations in drinking water, are given in Table 2. Our previously published values have been corrected for the changes made by Handbook 69 for the maximum permissible concentrations in drinking water. It will be noted that the permissible sea water concentrations for S^{35}, Ca^{45}, and Sr^{90} are larger by factors of 15 to 30 than the maximum permissible concentrations for drinking water. The stable isotopes of these elements are present in relatively large amounts in the oceans, and they are not greatly concentrated by marine organisms. On the other hand, such substances as P^{32}, Fe^{59}, Co^{60}, Zn^{65}, and Ce^{144} have permissible sea water concentrations 1/1,000 to 1/10,000 of the maximum permissible concentrations for drinking water. Here, the quantities of the stable isotopes in sea water are quite small, and these elements are heavily concentrated by marine organisms.

The method of computation used herein gives higher permissible sea water concentrations for S^{35}, Ca^{45}, Fe^{55}, Sr^{90}, and I^{131} than those in our two previous reports(2, 3). The difference in the permissible sea water concentration of Sr^{90} is particularly significant. Evidently, much larger quantities of this dangerous bone-seeker can be disposed of in sea water than had previously been supposed.

TABLE 1.—CALCULATED PERMISSIBLE CONCENTRATIONS OF RADIOISOTOPES IN LARGE VOLUMES OF SEA WATER.

Case I. Gastro-intestinal Tract is Not Critical Body Organ for Drinking Water
(Tentatively accepted values indicated by asterisk)

Isotope	Radio-active half-life	Bio-logical half-life in human body	Total body burden for the next most criti-cal organ for general population	Abun-dance of ele-ment in human body	Abun-dance of ele-ment in sea water	Concen-tration factor in marine organ-isms	MPC in drinking water for G.I. tract for gen. pop.	Permissible sea water concentration: From eq. (5b)	Permissible sea water concentration: From eq. (6a)
	(days)	(days)	(μc)	(g)	(g/ml)		(μc/ml)	(μc/ml)	(μc/ml)
P^{32}	14	1,200	0.6 (bone)	5.3×10^{2}	1×10^{-7}	2×10^{5}	9×10^{-6}	9.6×10^{-8}	* 4.5×10^{-9}
S^{35}	87	22	9.0 (testes)	9.0	9×10^{-4}	5	5×10^{-8}	* 1.1×10^{-8}	1×10^{-2}
Ca^{45}	164	18,000	3.0 (bone)	1.06×10^{3}	4×10^{-4}	20	4×10^{-4}	* 1.2×10^{-4}	2×10^{-4}
Fe^{55}	950	65	100 (spleen)	3.9	5×10^{-8}	10^{4}	3×10^{-8}	* 1.4×10^{-6}	3×10^{-6}
Zn^{65}	250	23	6.0 (total body)	4.6	5×10^{-9}	5×10^{3}	2×10^{-4}	* 7×10^{-9}	4×10^{-7}
Sr^{90}	10,000	3,900	0.2 (bone)	6.7×10^{-1}	8×10^{-6}	20	5×10^{-5}	* 3.3×10^{-6}	2.5×10^{-5}
I^{131}	8	180	0.07 (thyroid)	5.2×10^{-2}	5×10^{-8}	10^{2}	1×10^{-8}	* 1.6×10^{-6}	1×10^{-4}
Cs^{137}	9,800	17	3.0 (total body	2.7	1.2×10^{-7}	50	8×10^{-4}	* 1.3×10^{-7}	1.6×10^{-4}

Case II. Gastro-intestinal Tract is Critical Body Organ for Drinking Water
(Tentatively accepted values indicated by asterisk)

Isotope	Radio-active half-life	Bio-logical half-life in human body	Total body burden for the next most criti-cal organ for general population	Abun-dance of ele-ment in human body	Abun-dance of ele-ment in sea water	Concen-tration factor in marine organ-isms	MPC in drinking water for G.I. tract for gen. pop.	Permissible sea water concentration: From eq. (5b)	Permissible sea water concentration: From eq. (6a)
	(days)	(days)	(μc)	(g)	(g/ml)		(μc/ml)	(μc/ml)	(μc/ml)
Cr^{51}	28	110	80 (total body)	4.3×10^{-4}	6×10^{-11}	10^{3}	2×10^{-8}	5.4×10^{-5}	* 2×10^{-6}
Fe^{59}	46	65	2 (spleen)	3.9	5×10^{-9}	10^{4}	6×10^{-5}	* 6×10^{-9}	6×10^{-8}
Co^{60}	1,900	9	1 (total body)	6.2×10^{-4}	5×10^{-10}	10^{4}	5×10^{-5}	8×10^{-7}	* 5×10^{-8}
Nb^{95}	35	50	4 (total body)	8.8×10^{-4}	3×10^{-9}	2×10^{2}	1×10^{-4}	3×10^{-5}	* 5×10^{-6}
Ru^{106}	365	20	0.3 (kidney)	6.0×10^{-3}	3×10^{-9}	10^{3}	1×10^{-5}	1.6×10^{-7}	* 1×10^{-7}
Ce^{144}	275	500	0.5 (bone)	1.8×10^{-1}	2×10^{-9}	8×10^{3}	1×10^{-5}	1.5×10^{-8}	* 1×10^{-8}

4. *Research Recommendations.*

The Committee on the Biological Effects of Atomic Radiation on Oceanography and Fisheries contributed a chapter entitled "Artificial Radioactivity in the Marine Environment" to the NAS—NRC Committee on Oceanography's report "Oceanography—1960–1970"(4).

This chapter contained detailed recommendations for research needed to develop policies and regulations controlling the introduction of radioactive materials into the oceans.

The report pointed out that estuaries and coastal waters must inevitably be of vital concern. They are the areas most likely to become contaminated and are the regions where the greatest hazard to human populations may arise. The deep waters of the open ocean, because of their isolation and tremendous volume, may ultimately prove useful for the disposal of large amounts of radioactive materials. Studies of both the shallow coastal areas and the open ocean will involve intensive field measurements as well as laboratory experiments.

TABLE 2.

Comparison of Permissible Sea Water Concentrations Computed in Table 1 with Values Published in NAS–NRC Publications 655 and 658, and with MPC Values for Drinking Water in Handbook 69.

Isotope	MPC for drinking water for gen. pop.	Permissible sea water concentration from NAS—NRC Pubs. 655 and 658 *	Tentative permissible sea water concentration from Table 1
	(μc/ml)	(μc/ml)	(μc/ml)
P^{32}	2×10^{-5}	5×10^{-9}	4.5×10^{-9}
S^{35}	6×10^{-5}	1.2×10^{-4}	1.1×10^{-3}
Ca^{45}	9×10^{-6}	9×10^{-6}	1.2×10^{-4}
Cr^{51}	2×10^{-3}	2×10^{-5}	2×10^{-5}
Fe^{55}	8×10^{-4}	8×10^{-7}	1.4×10^{-6}
Fe^{59}	6×10^{-5}	6×10^{-8}	6×10^{-9}
Co^{60}	5×10^{-5}	5×10^{-8}	5×10^{-8}
Zn^{65}	1×10^{-4}	2×10^{-7}	7×10^{-9}
Sr^{90}	1×10^{-7}	5×10^{-8}	3.3×10^{-6}
Nb^{95}	1×10^{-4}	5×10^{-6}	5×10^{-6}
Ru^{106}	1×10^{-5}	1×10^{-7}	1×10^{-7}
I^{131}	2×10^{-6}	2×10^{-7}	1.6×10^{-6}
Cs^{137}	2×10^{-5}	4×10^{-6}	1.3×10^{-7}
Ce^{144}	1×10^{-5}	1×10^{-8}	1×10^{-8}

* Corrected after publication for change in MPC for drinking water.

Coastal and Estuarine Environments

A large number of internal and external factors combine to determine the characteristics of an individual estuary or coastal region. Studies of a single estuary, or of a single coastal area, will not suffice to provide general, basic concepts applicable to all inshore environments. However, enough is now known about estuarine environments that it is possible to deduce the circulation pattern from a knowledge of the fresh water inflow (which, in case of excess evaporation, may be negative), morphology, tidal flow, and salinity distribution. On the basis of these parameters, estuaries can be grouped into characteristic types. Detailed studies should be made of at least four estuaries representing the characteristic types around the North American continent.

The same general arguments can be applied to the coastal waters, including continental shelves and offshore banks. Coastal waters are highly variable in both space and time and must be classified in terms of such factors as the character of the coastline, the bottom topography, the tidal currents, the general circulation, and the land run-off and climatic features. Systematic studies should be made of at least five coastal areas characteristic of the different types of waters bordering the North American continent.

These investigations can best be accomplished by individual agencies concentrating upon areas close at hand. It will require at least five years of intensive studies to provide adequate understanding of the estuarine and coastal waters.

The Open Ocean

Significant amounts of radioactivity may be introduced into the open ocean in scientific and engineering tests, through sinkings of nuclear-powered vessels, and by the disposal of wastes from power reactors. At the present time, on the basis of fragmentary information, it is possible to make only vague estimates of the fate of radioactive isotopes introduced in the deep ocean. Too little is known concerning the circulation and mixing processes in the surface layers and in the deeper, more homogeneous waters of the great ocean basins to evaluate accurately either the rate of dispersal near the surface or how rapidly materials introduced at great depths will be transported by mixing and vertical currents into the surface layers where they will be concentrated by marine organisms. Many physical, chemical, biological, and geological processes are involved and must be studied in detail. To provide the essential information, comprehensive oceanographic investigations need to be made by all maritime nations.

Ocean Processes

The two programs outlined above will provide essential information on the regional characteristics of the shallow estuarine and coastal areas and on the currents and mixing processes in the waters of the open ocean. Alterations in physical state, together with solution, precipitation, and interaction with sedimentary particles, will affect the fate of the materials. Some of these processes can be studied at sea but others can be more profitably investigated in shore laboratories where there are specialists and the necessary complex equipment. Field and laboratory studies are also essential to establish the biological half-lives of radioactive materials in marine plants and animals and the biological pathways involved in the uptake, concentration, and retention of the individual isotopes. As section 3 shows, these are more important than the concentration factors that have been the principal subject of study in the past.

5. *Radioactive Materials Introduced into the Irish Sea and the Columbia River.*

The most important radiation exposure that a significant fraction of the population is apt to receive from the existence of radioactive materials in the sea will probably originate from fish, shellfish, seaweed, or other products consumed as food. To assure that the quantities of radioisotopes consumed with these products do not exceed allowable amounts, certain limits must be established for the quantities of individual isotopes that can be added to a given body of sea water. The selection of suitable limits is complicated by the different behavior of the radioelements under various environmental conditions, the types of foodstuffs which are harvested from a specific area, the rate of consumption of these products by individuals, and the contribution that other sources of radiation make to the overall exposure received by the population involved.

Where no previous experience is available for the particular area involved, permissible limits must be predicted on the basis of field or laboratory observations made elsewhere and on assumptions that large quantities of the marine products are consumed by individuals. It was necessary for working groups of this Committee to use such criteria in the computation of maximum permissible quantities of certain isotopes in sea water that might result from releases from nuclear-powered ships(3) or from packaged wastes deposited in the coastal waters of the Atlantic or Gulf of Mexico(2).

Where there has been carefully controlled release of waste of known composition and comprehensive monitoring of the radioactive materials that result in the water and in the biological species important to man, many of the uncertainties inherent in complex extrapolations can be eliminated. Permissible concentrations in the water and, in turn, appropriate rates of release of radioactive wastes can be established with a high degree of confidence directly from the observed concentrations in the species of interest. At this time, such experience is available from two large installations: one is the Windscale Works in England which discharges fission-product type waste through a 3-kilometer long pipeline into the Irish Sea, the other is the Hanford Operations in the United States which discharges reactor effluent containing neutron-activated materials into the Columbia River.

The British state(7) that they originally considered the discharge of a few hundred curies per month into the Irish Sea. They concluded from a preliminary investigation that a discharge of about 100 c/day of beta activity and of about 0.1 c/day of alpha activity would be completely safe. After experience was gained during the early years of operation through careful monitoring of the shore, sea bed, and edible marine products, a reassessment showed that discharges of nearly 1000 c/day of beta activity and of a few curies of alpha activity would be safe provided the discharge of ruthenium-106 was restricted to 8,000 c/28 days and strontium-90 was restricted to 2,800 c/28 days. They suggest from more recent work that it would be possible to discharge safely as much as 100,000 c/month. Their actual mean discharge for the last ten months of 1957 is reported as 4,549 total beta c/28 days (approximately 160 c/day).

The effluent from the cooling system of the production reactors at Hanford is discharged to the Columbia River after a single pass through the fuel channel. This discharge has been monitored by extensive measurements of the river water, aquatic life, and other products through which the radioactive materials might provide exposure to persons living in the environment of the plant(8). Such monitoring, maintained over a period of years, has permitted correlations between the exposure reaching local inhabitants through a variety of pathways and the quantities of waste released. Management of the waste on the point-of-exposure basis has thus been possible.

During 1957, the neutron activation products released to the Columbia River were of the order of 2000 c/day* in terms of gross beta emitters measured at Pasco, some 35 miles downstream from the reactors and some 200 miles above the mouth of the river. A large part of this activity originates from very short-lived isotopes which have significance in the exposure received by persons who live near the Hanford plant and drink Columbia River water. This quantity of activity is, of course, dispersed throughout a very large volume of river water and thus the concentration in terms of microcuries per milliliter is well below the permissible levels. These isotopes, with half-lives of a few days or less, are not of significance by the time the river water reaches the ocean more than two weeks later. A few isotopes with longer half-lives are present in significant amounts. The values listed in Geneva paper 743(8) would indicate a daily discharge in the vicinity of Pasco of about 1000 c/day of Cr^{51}, and 15 c/day each of P^{32} and Zn^{65}. Since there is a high concentration of P^{32} by biological processes, this is

* Estimated from data published in Geneva Paper 743(8) and typical discharge rates for the Columbia River.

the major radioisotope in Columbia River fish. The concentrations of Zn^{65} and Cr^{51} in the fish are considerably lower(9).

Monitoring data indicate that the exposure to persons living in the vicinity of the plant and who eat fish caught from the river is below permissible limits. Concentrations of radioisotopes in the waters off the mouth of the Columbia River will be substantially less than in the river near the plant, not only because of additional radioactive decay but also because of retention of the isotopes in river silt and biota, and additional dilution.

The experiences at Hanford and Windscale illustrate that it may be possible to release radioactive materials to the marine environment with safety in significantly greater amounts than one could predict from preliminary information. Each environment presents a different set of conditions, however, and increase of releases at specific sites should be undertaken with caution and extensive monitoring. Because of the need for relatively precise data on the radiation exposures associated with waste discharge and for further knowledge of safe concentrations of various isotopes in the water, it is recommended that comprehensive monitoring programs be carried out at all future atomic energy installations that discharge substantial amounts of radioactive waste into marine or fresh water environments.

6. *Recent Developments in our Knowledge of the Deep Sea and in Field Measurement Techniques.*

Significant advances, pertinent to problems of the distribution of radioactivity in the oceans, have been made in two general fields: the measurement of water mass movements and the activity levels of man-produced isotopes in the oceans. Several papers,(10, 11, and 12) for example, have appeared on the uptake of elements, principally the heavy metals, by marine organisms, and the results have elaborated and extended previously obtained knowledge. In addition, the development of deep-sea cameras(13) has reached the point where it is quite feasible to use these instruments to study the integrity of waste containers on the sea floor.

Although the knowledge of the circulation of the deep ocean has increased in the past few years, the data are still too scarce and scattered to permit construction of a coherent picture. Carbon-14 measurements in the Pacific by Rafter, Fergusson and others in New Zealand(14) and by Suess in the United States(15) have confirmed earlier speculation that the deep waters of the Pacific are much older than those of the North Atlantic. Rafter and Fergusson report the average C^{14} age of South Pacific water below 300 m to be greater than 1000 years. Suess' measurements in the eastern Pacific show a regularly increasing age of the deep water from 1500 years at 47° S to about 1900 years at 15° N. Wooster and Volkman(16) have shown that the bottom water of the eastern North Pacific is the oldest in the open Pacific. Broecker's C^{14} measurements of Atlantic circulation(17) indicate the deep waters have ages of the order or 10^3 years or less.

Within the last few years numerous measurements of the flow in the intermediate and deep layers have been made. Most of the deep observations have been made with the Swallow neutrally-buoyant float. Using this instrument in the Pacific, Knauss(18) has described the Equatorial Undercurrent, which, at a depth of about 100 m, has an eastward transport along the equator of about 30×10^6 m^3/sec and speeds of 100–150 cm-sec. Knauss(19) has also found a strong eastward flow under the Equatorial Countercurrent, with a transport of about 30×10^6 m^3/sec and speeds of 15–20 cm/sec in the water below the thermocline and extending to 800 m or deeper. In the Atlantic, currents of 2–5 cm/sec have been observed at depths of 2000–4000 meters(20), and Swallow and Worthington(21) have described a deep countercurrent underlying the Gulf Stream with speeds up to 18 cm/sec at depths of several thousand meters. These and other recent (unpublished) measurements suggest that horizontal exchange at intermediate and greater depths is far more rapid than had hitherto been realized.

A technique complementary to these more popular methods for the study of near-bottom deep-sea circulations involves the use of isotopic analyses of lead and thorium isotopes in deep-sea sediments. The transfer of dissolved chemical species, characteristic of water mass adjacent to the bottom, to one or more of the solid phases of the deposit results in a record in the sediments of the travels of the bottom water. Goldberg, Chow, and Patterson(22, 23, and 24) have used two groups of isotopes, those of lead and thorium, to subdivide the bottom waters of the Pacific into four domains presumed to reflect the points of origin of the lead and thorium isotopes in the bottom waters, these species having been introduced as a result of continental weathering. Four distinct regions in the Pacific appear, roughly classified as West, Central, East, and South Pacific, all differing from the Atlantic which at present appears to be but one domain. The data so far establish that bottom waters in the Pacific are incompletely mixed in times of the order of a million years or less.

Recently, Koczy(25) has used the observed distribution of radium in the ocean to evaluate the rate of mixing between deep and surface waters. Under the assumption that all radium in ocean water originates from the sea floor, a simplified form of the Fickian diffusion equation is used to compute deep vertical eddy diffusivity coefficients, which are found to be about 8 cm^2/sec. In the layer of minimum eddy diffusion (700–1500 m), vertical transfer of radium is due to advection, which is estimated at 0.7–2.0 m/yr. These results have been used to compute the consequences of depositing large quantities of Sr^{90} on the sea floor. It is shown that at the top of the deep layer, the maximum concentration of Sr^{90} is reached in about 25 years when the concentration per cm^3 is $10^{-2} \times Q$, where Q is the total amount of waste deposited on the sea floor.

Application already has been made of tagging indicators for the study of sea-water movements. A dye (fluoroscein) has been used to plot the dispersion of reactor effluent in the Irish sea, and artificial radioisotopes have been used in several small-scale experiments for following the movement of sediments and wastes. The problem of tagging water masses in the open sea has been discussed in some detail by Folsom and Vine(1). Because of the immense size of the ocean, and because of the difficulty usually experienced in establishing ships' positions accurately, small-scale tagging experiments are difficult to carry out, and usually it is necessary to prepare for the detection of the tagging material after extreme dilution. The tagging material must never present a real human hazard—and frequently must avoid even the appearance of being a hazard. For these reasons, considerable research effort has centered around improving the techniques for detecting minute traces of dyes and artificial nuclides at sea.

Several institutions are doing work fundamental to the improvement of underwater gamma-ray detectors. Large liquid scintillometers, plastic scintillometers, coincident gamma-ray detectors, and portable pulse-height spectrometers are now under development for this application.

Information is being collected, compiled, and studied concerning the character and magnitude of the gamma-ray background in the marine environments.

It is apparent that several useful water-tagging studies could be done in deep water using as tagging material only those cheap wastes that some day may be dumped at sea; nevertheless, it is most desirable to avoid all uneasiness by the use of only short-lived isotopes in the early tests. Recently, small reactors have been offered for installation on research ships (or shore stations), and it appears that quite adeqate amounts of Na^{24} (14 hr), Rb^{86} (18 days), and other short-lived isotopes can be made available to the oceanographer under suitable conditions. These small reactors would serve further to improve sensitivity in the detection and identification by affording means for making activation analyses.

A remarkable dye-tagging procedure has just been announced by J. H. Carpenter(26). It has been discovered that the readily available, stable, and commercial dye, Rhodamine B, can be detected after dilution to the level of 2 parts in 10^{12} (i.e., 2×10^{-3} ppb). This dye is safe, and it is inexpensive (about $5 per pound). The dye is detected by use of a modification of a standard fluorimeter. The technique has been used already (to dilutions of 0.05 ppb) in studying wake motions and surface water movements in estuarine waters, and has proven very successful even under unfavorable field conditions where much silt was present in the water. It is reported that this dye is far more stable than any other previously used, and that it can be expected to persist in the sea for months. Because of the sensitivity afforded, the low cost, and the absence of all human hazard, it appears that this technique will be of real and immediate use at sea either as the sole tagging agent or together with radioactive tags. Efforts are now being made to develop a suitable *in situ* detecting instrument.

To follow water movements in detail in the open sea, it is necessary to call upon electronic position-indicating equipment of a type not necessary in usual navigation. Several satisfactory electronic systems for positioning a ship have been demonstrated; however, few American oceanographic expeditions have yet been able to afford the large investment required to obtain the ship's position to the desired accuracy. This is especially true where the survey includes stations several hundred miles from shore. Anchored buoys and acoustic markers can also be used to solve off-shore navigation and detection problems.

TABLE 3—EXAMPLES OF RECENT MEASUREMENTS OF LEVELS OF LONG-LIVED ARTIFICIAL ACTIVITIES IN SURFACE SEA WATER

Isotope	Location	Date	Activity Level (d/m/l)	Reference
Cs^{137}	Coastal waters off Japan	1958	0.15 — 0.33	(27)
	"	1959	0.84	(28)
	Southern California coastal waters	Dec. 1959	0.1	(29)
Sr^{90}	Sargasso Sea	July 1958	0.091 ± 0.006	(30)
Ce^{144}	"	"	0.544 ± 0.01	(30)
Pm^{147}	"	"	0.072 ± 0.007	(30)

IV. References

1. *The Effects of Atomic Radiation on Oceanography and Fisheries,* NAS–NRC Pub. 551, 1957.
2. *Radioactive Waste Disposal into Atlantic and Gulf Coastal Waters,* NAS–NRC Pub. 655, 1959.

3. *Radioactive Waste Disposal from Nuclear-Powered Ships,* NAS–NRC Pub. 658, 1959.
4. "Artificial Radioactivity in the Marine Environment," Chap. 5, *Oceanography, 1960 to 1970,* NAS–NRC, 1959.
5. *Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure,* Report of the National Committee on Radiation Protection and Measurements, National Bureau of Standards Handbook 69, Superintendent of Documents, 1959.
6. *Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water,* Report of the National Committee on Radiation Protection and Measurements, National Bureau of Standards Handbook 52, Superintendent of Documents, 1953.
7. Dunster, H. J., "The disposal of radioactive liquid wastes into coastal waters," Paper 297, *Proceedings of the Second International Conference on Peaceful Uses of Atomic Energy, Geneva,* 1958.
8. Healy, J. W., Anderson, B. V., Clukey, H. V., and Soldat, J. K., "Radiation exposure to people in the environs of a major production atomic energy plant," Paper 743, *ibid.*
9. Davis, J. J., Perkins, R. W., Palmer, R. F., Hanson, W. C., and Cline, J. F., "Radioactive materials in aquatic and terrestrial organisms exposed to reactor effluent water," Paper 393, *ibid.*
10. Bien, R., and Krinsley, D. H., "Trace elements in the pelagic tunicate, D. H. *Velella lata," Marine Research* **16**, 246–56 (1958).
11. Rice, T. R., and Willis, V. M., "Uptake, accumulation and loss of radioactive cerium-144 by marine planktonic algae." *Limnology and Oceanography* **4**, 277–90 (1959).
12. Nicholls, G. O., Curl, Hurbert, and Bowen, V. T., "Spectrographic analyses of marine plankton," *ibid,* 472–79 (1959).
13. Preprints from *International Oceanographic Congress* in Section on Origin, Distribution, Constituents and Processes Affecting Deep-Sea Sediments, pp. 445–495, 1959.
14. Rafter, T. A., and Fergusson, G. J., "Atmospheric radiocarbon as a tracer in geophysical circulation problems," *Proceedings of the Second International Conference on Peaceful Uses of Atomic Energy, Geneva,* **18**, 526–532 (1958).
15. Suess, H., Rakestraw, N. W., and Oeschger, H., "Apparent age of deep water in the Pacific Ocean," Preprints from *International Oceanographic Congress,* pp. 440–441 (1959).
16. Wooster, W., and Volkman, G. H., Unpublished manuscript, Scripps Institution of Oceanography, La Jolla, California.
17. Broecker, W. S., "Geochemistry and physics of circulation," Paper presented at International Oceanographic Congress, 1959.
18. Knauss, J. A., and King, J. E., "Observations of the Pacific-Equatorial Undercurrent," *Nature* **182**, 601–2 (1958).
19. Knauss, J. A., and Pepin, R., "Measurements of the Pacific-Equatorial Countercurrent," *Nature* **183**, 380 (1959).
20. Swallow, J. C., and Hamon, B. V., "Some measurements of deep currents in the Eastern North Atlantic," Preprints from *International Oceanographic Congress,* pp. 442–443 (1959).

21. Swallow, J. C., and Worthington, L. V., "The deep countercurrent of the Gulf Stream off South Carolina," *ibid,* 443–444 (1959).
22. Chow, T. J., and Patterson, C. C., "Lead isotopes in manganese nodules," *Geochem. Cosmochem. Acta* **17**, 21–31 (1959).
23. Goldberg, E. D., and Koide, M., "Ionium-thorium chronology in deep sea sediments of the Pacific," *Science* **24**, 1003 (1958).
24. Goldberg, E. D., Patterson, C., and Chow, T., "Isotope ratios as indicators of oceanic water masses," *Proceedings of the Second International Conference on Peaceful Uses of Atomic Energy, Geneva,* **18**, 347–351, (1958).
25. Koczy, F. F., "Natural radium as a tracer in the ocean," *ibid,* 351–357 (1958).
26. Carpenter, J. H., Chesapeake Bay Institute, Johns Hopkins University, November, 1959, personal communication.
27. Yamagata, N., and Matsuda, S., "Cesium-137 in the coastal waters of Japan," *Bull. Chem. Soc. Japan* **32**, No. 5, 497 (1959).
28. Yamagata, N., and Matsuda, S., Presented at meetings of Subcommittee on Radioactivity in the Ocean, Special Committee on Oceanic Research, New York, 2 Sept. 1959.
29. Folsom, T., and Mohanrao, G., Unpublished preliminary gamma-ray measurement, Scripps Inst. of Oceanography, La Jolla, California.
30. Bowen, Vaughn, Presented at meeting of Subcommittee on Radioactivity in the Ocean, Special Committee on Oceanic Research, New York, September 1959.

R. REVELLE, *Chairman*
DAYTON E. CARRITT
WALTER A. CHIPMAN
LAUREN R. DONALDSON
RICHARD H. FLEMING
RICHARD F. FOSTER
EDWARD D. GOLDBERG
BOSTWICK KETCHUM
LOUIS A. KRUMHOLZ
CHARLES E. RENN
MILNER B. SCHAEFER
ALLYN C. VINE
LIONEL A. WALFORD
WARREN S. WOOSTER

Consultants
THEODORE R. FOLSOM
ALLYN SEYMOUR

The National Academy of Sciences—
National Research Council

The National Academy of Sciences—National Research Council is a private non-profit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare.

The Academy itself was established in 1863 under a Congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the Federal Government in scientific matters. This provision accounts for the close ties that have always existed between the Academy and the Government, although the Academy is not a governmental agency.

The National Research Council was established by the Academy in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the Academy in service to the nation, to society, and to science at home and abroad. Members of the National Research Council receive their appointments from the President of the Academy. They include representatives nominated by the major scientific and technical societies, representatives of the Federal Government, and a number of members-at-large. More than 3000 of the foremost scientists of the country cooperate in the work of the Academy-Research Council through service on its many boards and committees in the various fields of the natural sciences, including physics, astronomy, mathematics, chemistry, geology, engineering, biology, agriculture, the medical sciences, psychology, and anthropology.

Receiving funds from both public and private sources by contribution, grant, or contract, the Academy and its Research Council thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the Government, and to further the general interests of science.