EXPOSURE TO RADIATION IN AN EMERGENCY

National Committee on Radiation Protection and Measurements

Report No. 29

REPORTS OF THE NATIONAL COMMITTEE ON RADIATION PROTECTION AND MEASUREMENTS

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1958 "Maximum Permissible Radiation Exposures to Man," *Health Physics*, *1*:200, 1958; *Radiology*, *71*:263, 1958; and printed as an addendum to NBS Handb. 59 (1954).‡

1959 "Somatic Radiation Dose for the General Population, Report of the Ad Hoc Committee of the National Committee on Radiation Protection and Measurements," *Science*, *131*:482, 1962.‡

1960 "Suggested Regulations for Radiation Protection, Draft of Revision of Appendix B, NBS Handb. 61," *Atomic Industry Reporter, Laws and Regulations Volume, State Atomic Energy Regulations Section*, p. 207:11, January 25, 1961; and *Health Physics*, *5*:1, 1961.‡

* Out of print.
‡ Reprints not available.
† Available only from Section of Nuclear Medicine, Department of Pharmacology, The University of Chicago, Chicago 37, Illinois.

Exposure to Radiation in an Emergency

Recommendations of the National Committee on Radiation Protection and Measurements

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Report No. 29

Issued January 1962

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FOREWORD

The National Committee on Radiation Protection and Measurements (originally known as the Advisory Committee on X-ray and Radium Protection) was formed in 1929 upon the recommendation of the International Commission on Radiological Protection. The committee, governed by representatives of participating organizations consists of a Main Committee and nineteen subcommittees. Each of the subcommittees is charged with the responsibility of preparing recommendations in its particular field. The reports of the subcommittees require approval by the Main Committee before publication.

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Subcommittee 7.	Monitoring Methods and Instruments, A. R. Keene.
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Subcommittee M-3. Standards and Measurement of Absorbed Radiation Dose, H. O. Wyckoff.

Subcommittee M-4. Relative Biological Effectiveness, V. P. Bond.

PREFACE

In 1954 the Federal Civil Defense Administration made an informal request that the National Committee on Radiation Protection and Measurements develop some information as to the doses that might be accepted by several categories of civil defense workers under emergency conditions. In compliance with the request, an *ad hoc* group of the NCRP provided the FCDA with specific information of an interim nature. Up to the present, the federal civil defense officials have used the information provided by the NCRP, always accompanying it by the statement that the information was of an interim nature.

In 1955 a formal request from Mr. Val Peterson, Civil Defense Administrator, asked if the NCRP would undertake a broad study of the emergency exposure problem, with particular reference to conditions that might result from a nuclear attack. After a review of the request by the Executive Committee of the NCRP, it was decided to establish a new subcommittee to study the problem. Initially, attention was focused on the extent to which whole-body gamma radiation (a) caused injury, (b) impaired the capacity to work, (c) reduced fertility, (d) caused late somatic effects such as leukemia, life-shortening, etc., and (e) caused genetic injury. The subcommittee examined in detail the problem of stipulating values for permissible dose for selected personnel engaged in tasks of varying priority during the postattack period. It soon became apparent that this approach—however commendable in the case of a radiation accident in peacetime—was not realistic in a thermonuclear war. In retrospect, it is evident that the magnitude of the situation was not fully appreciated when the subcommittee first examined the question of "the amount of radiation that might be accepted" (1955). Studies such as the Rand Corporation civil defense report of 1957 convinced the subcommittee that the real problem was survival. The question then became "How much radiation can people stand?"—not how much is acceptable or permissible. The entire subcommittee shared with many others "the enormous psychological difficulty which everybody has of coming to grips with the concept of thermonuclear war as a disaster that may be experienced and recovered from." After considerable debate within the subcommittee, it was decided to take an entirely different approach and to prepare material directed primarily to the problems that might be encountered in widespread civil defense operations. At the same time, it was obvious that many of the same principles could be applied to less extensive civil radiation disasters under peacetime conditions.

The present handbook was prepared by the Subcommittee on Permissible Exposure Doses under Emergency Conditions, with the following members and consultants:

Members	Consultants
Chairman, G. V. LeRoy	C. B. Braestrup
H. A. Blair	R. F. Brown
G. W. Casarett	J. C. Bugher
G. M. Dunning	A. H. Dowdy
E. L. Green	L. H. Garland
R. J. Hasterlik	L. H. Hemplemann
L. S. Taylor	R. D. Huntoon
E. C. Williams	H. M. Parker
	G. A. Sacher
	R. S. Stone
	Shields Warren

Lauriston S. Taylor, Chairman
National Committee on Radiation Protection and Measurements
Washington, D.C.
October 27, 1961

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1. INTRODUCTION

1.1. The Problem

Over the last 32 years, the National Committee on Radiation Protection and Measurements has developed a philosophy and criteria for the maximum permissible occupational exposure of radiation workers to ionizing radiations. The basic premise in these criteria is that the exposure, continued over a working lifetime (50 years), is not expected to result in any detectable injury to the individual. More recently (1956-57), additional criteria, applicable to both radiation workers and the general public, have been established for the purpose of minimizing the possibility of deleterious effects of radiation on life-span and heredity. All such criteria are designed to deal with situations in which someone has control over the source of radiation, the exposure of persons to the radiation, or both. Radiation exposure levels considered in these criteria are very low—generally less than an average of 0.1 rem/week except under a few special circumstances. For most conditions encountered in everyday uses of radiation, the criteria are considered to be adequate and reasonable.

Emergency situations can occur, however, wherein large numbers of people may be heavily exposed to radiation under circumstances largely beyond their control. Such exposure may result from a nuclear war or, for a limited region, from the breakdown of a nuclear reactor or an accident in a nuclear energy industrial establishment. In disasters of this sort, the concept of permissible exposures cannot be applied in the usual sense.

The recommendations for handling a radiation emergency represent a departure from the earlier objectives of the NCRP, in which the principal emphasis has been upon the prevention of significant radiation injuries to man from exposures extending over long periods of time. Here we are concerned with possible exposures greatly in excess of those encountered in normal radiation work and, in the case of nuclear war, with the certainty that radioactive fallout will kill or injure many of those in the areas involved. Furthermore, in a radiation emergency, the initial exposure will surely be accidental and thus under little or no control, whereas later exposure may be subject to some degree of supervision and planning. Such operations as rescue, salvage, reconstruction, and reoccupation of contaminated areas should be conducted so that control of exposure is possible.

The problems of controlling exposure to radiation in a nuclear war are inordinately complex, and their solution is not susceptible to rules of thumb or to the principles of radiation protection based on past experience. It is not possible, for example, to assign values for "permissible dose." In the first place, it is realistic to expect that during the attack phase many people will receive doses in excess of the amount that a committee (the NCRP, for example) might stipulate for the highest-priority task. What does the civil defense commander do when his key personnel have already received the "permissible dose" and there is still important work to be done? Further, it seems obvious that the privileges of a civil defense commander and a military commander should be similar with respect to decisions involving the risk to subordinates of injury or death. Who would accept an assignment as the commander of a fortress or of a warship if his actions were limited in advance by rules prescribed by a committee which did not have the authority to appoint him and was not responsible for the manner in which he discharged his duties? The alternative to prescribing permissible doses for specific tasks or for specific groups of people is to prepare guidelines describing the consequences of exposure to the amounts of radiation that might be encountered. The commander then becomes the decision-maker with respect to the people for whom he is reponsible. He is urged to

limit the exposure of everyone to the greatest extent possible. He is told the approximate consequences of various doses of radiation. It is up to him to decide how he will deal with the radiation problem, just as it is up to him to decide how he will provide water, food, medical care, and other essential services.

This report was prepared to help civil defense officials make proper decisions in preparation for nuclear warfare and during the first few months after an attack. It is not a scientific treatise; rather it is a part of the recipe for survival. The committee has attempted to describe the important characteristics of radiation and radioactive fallout so that they can be understood by people who do not have special training in radiological physics and biology. The recommendations must be regarded as reflecting the committee's best effort to evaluate information presently available; the ideas may be extensively modified as our knowledge increases. In general, there is little precise information on the over-all effects of large radiation exposures on man.

1.2. Assumptions

a. The members of the National Committee on Radiation Protection and Measurements would not issue this report if they were not firmly convinced that appropriate actions would reduce the toll of casualties from a radiation emergency, regardless of cause and regardless of size. They are confident that even the widespread fallout after an attack with high-yield nuclear weapons need not create a hopeless situation. The committee believes that enough is known about radiological physics and about the medical and biological effects of radiation to go far toward assuring the survival of the nation, if the knowledge is properly applied. However, the effective application of existing knowledge for civil defense presupposes many preparations made well in advance of the disaster. These include the development of (1) shelters adequately stocked with food and water; (2) a capability for radiation monitoring; and (3) an effective civil defense organization, including an adequate number of people having at least a basic knowledge of radiation hazards and safeguards.

b. This report was prepared so that it could be understood by the sort of person who is likely to be the responsible civil defense officer at any echelon of the system—local, state, regional, or national. In the United States he is usually a senior police or fire department officer or a retired member of the armed forces who has had command experience. Few such men have more than a modest knowledge of radiological physics or of the medical effects of radiation. Ideally, their training has qualified them to face danger bravely, to improvise in adversity, to make decisions affecting the security and the lives of others, and—above all—to command.

The NCRP assumes that such officials will have qualified technical assistants to perform functions comparable to those of the radiological officers and the medical officers on the staff of a military commander. The radiological group should be able to provide the kind of information needed for decision-making. The technical details of radiation monitoring, estimations of dose, and other radiological procedures are outside the scope of this report. Chapter 5, "Radiological Considerations," contains explanatory material to aid in the understanding and the application of information and estimates supplied by the technical staff. Likewise, the details of the diagnosis of radiation injuries and the treatment of casualties are beyond the scope of the report. Chapter 6, "Biological and Medical Considerations," contains explanatory material regarding the various aspects of sickness and injury caused by radiation. Attention is focused on the relation between the size of the dose, the seriousness of the effect, and the ultimate outcome. Although medical and scientific staff officers are expected to interpret and advise, decisions must ultimately be made by the official or the commander responsible for operations.

The report is also intended for subordinate civil defense personnel and, in particular, for those specialists in radiological

physics, medicine, and public health who may serve as advisers on the staff of the commander. It is important that all who participate in decision-making use the same language and understand each other. As a matter of principle, the report does not offer specific suggestions regarding operations. It is the opinion of the committee that operational plans and procedures are properly the responsibility of the civil defense organization.

c. The principal justification for a civil defense organization —and for this report—is to resist aggression and insure the survival of the United States in a nuclear war. Survival, therefore, is paramount, for without it there is no need to be concerned about late somatic and genetic effects of radiation. In the event of a nation-wide attack, there may be a tendency to think only of survival and disregard entirely the possibility that late somatic and genetic effects could impair the health of the people. Such an attitude, if allowed to dominate decision-making, may be shortsighted, although it should be realized that measures adopted to insure survival with the fewest possible casualties will be the same as measures effective in reducing late effects. Consequently, early command decisions based on survival alone are not likely, in general, to be in serious conflict with more leisurely judgments in which late effects are carefully considered. When circumstances permit, it is desirable to give preferential consideration to children and adults still capable of procreation, since these are the ones through whom the genetic effects of radiation will have the most adverse influence on the future population. In radiation emergencies in peacetime, there should never be any question about the need for preferential protection of the younger portion of the population.

1.3. Limitations

a. This report considers mainly the effects of whole-body irradiation from external sources of gamma radiation and injury to skin by beta radiation. The immediate effects will be responsible for most of the casualties in a disaster that involves radiation.

What is known about the quantitative effects of external gamma and beta radiation on normal people comes mostly from analysis of experience with radiation therapy, from studies of radiation accidents, and from the study of the Japanese who survived the atomic bomb attacks. Even though much of the information is indirect, more is known about radiation than about most other agents (e.g., war gas, blast, etc.) capable of causing mass casualties. Furthermore, reliable instruments are available to measure exposure to gamma and beta radiation.

b. In the event of a thermonuclear attack and with many peacetime accidents, neutron radiation may be generally neglected, since people exposed to it in lethal amounts will almost certainly be mortally injured by other effects—i.e., blast, fire, missiles, etc.

c. Most available evidence indicates that radioactive material taken into the body immediately after a nuclear attack will be less important than the whole-body exposure to gamma radiation. Whereas gamma-ray exposure can be estimated with some degree of confidence at any time, there will be an unpredictable interval after an attack during which it will not be possible to evaluate accurately the amount of radioactive material that may be inhaled or ingested. Since most of the information on the behavior of rarioactive material deposited internally is based upon animal experiments, the committee has chosen not to emphasize this aspect of an emergency. There are many ties between our experience with the effects of radiation on man and on experimental animals which permit limited confidence in extrapolations from one to the other. Even though there are serious gaps in our knowledge, this report presents such facts as are known, together with statements based on the best judgment of the committee. It has not been feasible to distinguish between the two.

Finally, it is intended that the information in this report is to provide a background for use in making decisions that will be needed during the period when an emergency actually exists. At

some reasonable time, the emergency measures should be terminated, and either normal or revised standards of radiation protection should be reinstituted.

2. EXPLANATION OF TERMS

2.1. Explanation versus Definition

For the purpose of this report, the NCRP prefers the expression "explanation of terms" to "definitions," since it permits the use of ordinary conceptual and operational statements rather than the precise radiobiological terminology used in its other reports. Obviously, the existence of an emergency does not affect the definition of such fundamental units as the roentgen, the rad, etc. The proper definitions of radiation quantities and units may be found in Appendix I. The terms explained in this chapter are those commonly used in this report. In Chapter 5, additional radiological terms are explained in the course of the discussion of radiation exposure. In Chapter 6, medical and biological terms are explained in connection with the description of the effects of radiation.

2.2. Emergency

A radiation emergency is an accident, or other event out of the ordinary, that threatens to expose people to more than 25 r in 1 week. It is not intended to include maintenance and reconstruction activities following a peacetime accident after the hazard to the general population has passed. It is expected that most radiation accidents in peacetime can be handled satisfactorily under the principles set forth in Handbook 59. Table 2.2 lists some of the possible causes of radiation emergencies and includes estimates of areas at risk.

2.3. Roentgen (r)

In dealing with radiation dosimetry, numerous physical quantities and units are necessary for proper description and understanding of the phenomena involved. Included are such terms as absorbed

TABLE 2.2. RADIATION EMERGENCIES

Situation	Possible Causes	Radioactive Material Released		Approximate Size of Radiation Field
		Approximate Quantity (Curies)	Characteristics	
1. Fallout from explosion of nuclear weapons a) Low-yield weapon b) High-yield weapon	Weapons test Accidental detonation War	a) Millions b) Thousands of millions	Typical young fission products (FP), plus material in which radioactivity was induced by neutrons	a) Hundreds of square miles b) Thousands of square miles (single weapon)
2. Accident to a power reactor a) Containment case b) Volatile release case c) 50 per cent release case	Mechanical failure Structural failure Operator error Natural disaster War	a) Millions b) Millions c) Millions	a) Gamma radiation only b) A radioactive cloud of noble gases c) Old FP, and volatile FP	a) Acres b) Depends on weather factors c) Thousands of square miles
3. Accident to a critical assembly, or experimental reactor	Mechanical failure Structural failure Operator error	Thousands	Typical young FP plus induced radioactivity Radioactive cloud	Square miles
4. Accident in a plant engaged in processing full elements, chemical separation of fission products, waste disposal, etc.	Mechanical failure Structural failure Operator error Explosion Natural disaster War	Millions	Old FP, or individual radionuclides Radioactive cloud	Square miles

dose (rad), exposure dose (roentgen), and RBE dose (rem). Conceptually, these are all different and in some cases apply only to specific radiations. However, for the purposes of this handbook and in consideration of all the other uncertainties and inaccuracies involved, the various terms can be considered as numerically about the same. Hence the term "roentgen," now being in common parlance, will be considered as synonymous for all the terms cited above. While the committee recognizes the possible danger of this usage, it believes that those readers knowledgeable in the basic principles will read in the strictly correct quantities and units where necessary.

2.4. Radiation

As used in this report, the term "radiation" refers primarily to the gamma (γ) rays and beta (β) rays emitted (a) during a nuclear explosion, (b) by fission products (FP), and (c) by material (radionuclides) in which radioactivity has been induced by neutrons.

The use of the unqualified term radiation herein always means gamma radiation; that emitted during the first minute of a nuclear explosion is termed initial radiation; and that emitted by fission products and by materials in which radioactivity has been induced is termed residual radiation.

2.5. Dose

The term "dose" by itself has various meanings. As used in this report, it refers to the radiation to which people may be exposed (more correctly, the exposure dose; see Appendix I). Loosely speaking, it is the same as an amount or a quantity of radiation. In this report the unit of radiation dose is the roentgen (r) or a subdivision of it, the milliroentgen (mr). 1 mr = 1/1,000 r.

The term exposure dose is usually qualified by "whole body" or "partial body" to indicate that the entire body or a limited portion of it is exposed to the radiation. In this report, the unqualified term means exposure of the whole body.

Dose rate is the rate at which a dose is delivered. In this report it is expressed in roentgens per hour (r/hr).

When personal dosimeters (such as pocket ionization chambers, film badges, etc.) are worn, the reading of the dosimeter gives the dose in roentgens or milliroentgens for the period worn. It is convenient to assume that the accumulated exposure dose and the dose received—or absorbed—by the individual are identical; but, strictly speaking, such is not the case. In an emergency situation, it is not practical to make the measurements and calculations that are needed to convert exposure dose (in roentgens) into absorbed—or tissue—dose (in rads). To simplify matters, it is assumed that in the case of a brief exposure to radiation lasting up to 4 days, the extent of the radiation injury is more dependent on the total dose than when exposure is protracted beyond 4 days. In the latter case, recovery (Sec. 2.11) from the injury leads to an increasing disproportion between the size of the accumulated dose and the extent of the clinical manifestations of radiation injury. In this situation, the equivalent residual dose (ERD), which is described in Section 2.6, is more useful than the accumulated dose for predicting the resultant illness and the chances of survival.

In this report for emergency conditions, an exposure that ranges in duration from a few seconds to 4 days is termed brief. When the period of continuous or intermittent exposure is longer than 4 days, it is termed protracted. These terms, applied to dose or exposure dose, are more appropriate than acute and chronic, respectively, which are used conventionally to describe the severity and duration of an illness or an injury.

2.6. Equivalent Residual Dose (ERD)

ERD is a concept that permits a more reliable prediction of the biological and medical consequences of exposure to radiation than is possible on the basis of the accumulated dose alone. By definition, ERD is the accumulated dose corrected for such recovery as has occurred at a specific time. It is presumed that a person who has received a particular ERD—expressed in r—will display approximately the same signs and symptoms of radiation injury as would be anticipated following a brief dose of the same size. The decision to use ERD to evaluate radiation exposure in an emergency is based on the following considerations: (1) it is not possible to predict the immediate effect of any amount of radiation unless one knows the manner and the duration of the exposure; (2) the body can repair a substantial fraction of the injury responsible for such immediate effects as acute radiation sickness; (3) recovery requires time; and (4) what injury cannot be repaired persists, and successive increments of the irreparable injury are cumulative.

Because quantitative information on the rate or the extent of recovery in man is limited, it is necessary to make certain assumptions on the basis of experiments with animals, in order to evaluate the effects of large protracted exposures such as may occur in an emergency. For the purpose of this report, therefore, the following assumptions are made:

(1) Ten per cent of the injury is irreparable and may cause the late effects described in Section 6.4b.

(2) The body recovers from the reparable 90 per cent of the injury in such a fashion that about half the recovery has occurred in 1 month and nearly all possible recovery has occurred after 3 months.

(3) The process of recovery is continuous in the case of protracted exposure.

(4) Since there are no proper units to describe radiation injury, it is convenient to consider that a brief dose and the injury that it causes are proportional in magnitude. Thus radiation injury equivalent to 100 r (for example) is sustained by a person who received a brief dose of 100 r. Likewise, the radiation injury expected as a result of an ERD of 100 r should be equivalent to that expected following the brief dose of the same size. With the passage of time after the onset of exposure, the occurrence of recovery

has the effect of canceling or subtracting an appropriate fraction of the accumulated dose. The amount of dose canceled varies with time after the onset of exposure but may never exceed 90 per cent. At any time, the dose that has not been canceled represents the injury inflicted by radiation and is reported as the equivalent residual dose (ERD).

The committee believes that the ERD should be used only to predict immediate effects, such as radiation injury or acute radiation sickness (see Sec. 6.4b) of the kind expected following brief doses in the range below 300 r. Although it may seem practical to use ERD to predict that additional protracted exposure may be fatal, it is not recommended. Similarly, there is no reason to suppose that ERD is a reliable predictor of any of the late somatic effects of radiation or of the genetic effects. The principal advantage to be gained from using ERD is to evaluate the combination of brief and protracted exposure that can be expected in most radiation emergencies. The dose already received at any time and the protracted exposure anticipated in the future can be combined readily to obtain an ERD, except that it is not recommended to extend the calculation beyond 1 year after the onset of the emergency. In the reconstruction phase after a nuclear attack, the ERD should be particularly helpful in controlling protracted exposure by adjusting the time permitted outside shelter.

For a particular situation, the ERD can be calculated on the basis of the assumptions stated above or it can be estimated by using Figures IIa and IIb in Appendix II. The extent to which the recovery process may reduce the accumulated dose is shown in Figure IIc, Appendix II, for situations in which the brief exposure dose ranges from 0 to 200 r and where the subsequent protracted exposure for periods up to 1 year ranges from 1 r per day to 10 r per day.

2.7. Quantity of Radioactive Material

The unit of quantity of a radioisotope—or a mixture of radioisotopes—is the curie. Related units are the megacurie (Mc), a million curies; the millicurie (mc), 1/1,000 of a curie; the microcurie (μc), 1/1,000,000 of a curie, etc. One curie is the quantity of any radioactive material in which the number of disintegrations per second is 3.7×10^{10}.

2.8. Maximum Permissible Limits of Exposure

The NCRP has formulated basic rules and recommendations concerning exposure to ionizing radiation. These apply to normal working and living conditions and are presumed to be subject to control. They do not apply to emergency conditions, although their achievement would be a desirable goal under any conditions. They are given here for reference purposes only. For external exposure, the maximum permissible dose (MPD) is defined in NCRP-NBS Handbook 59. Handbook 69 gives the maximum permissible body burden for each nuclide and the recommended values for maximum permissible concentration (MPC) in air and water.

For occupational external gamma-ray exposure of the whole body, bone marrow, gonads, or lens of eye, the basic rules are (1) MPD per calendar year = 5 roentgens (average); (2) MPD per calendar quarter = 3 roentgens (maximum); and (3) when records of occupational exposure are maintained, the basic rules permit proration of exposure, provided that the MPD per calendar quarter is not exceeded and provided that the maximum permissible accumulated dose (MPAD) does not exceed (N - 18) x 5 r, where N is age in years.

For occupational exposure of the thyroid or the skin of the whole body, the MPD is 30 r per year, and 10 r in any calendar quarter.

The MPD for the individual in the general population resulting from operations in a controlled area is 0.5 r per year. The limits for internal exposure are consistent as far as possible with these rules. Note that 50 years of occupational exposure at 5 r/yr is 250 r. The maximum non-occupational lifetime exposure in the

vicinity of a controlled area is about 35 r (0.5 r per year to age 70). These limits do not include the natural background radiation or exposure from medical or dental X-ray procedures.

2.9. Radiation Injury

The effects of amounts of radiation a few times greater than the permissible limits for occupational exposure can be detected only by statistical methods applied many years after the onset of exposure. It is important to appreciate the distinction between this subtle non-clinical type of injury and acute radiation sickness or damage to skin, which is apparent soon after the beginning of exposure to large amounts of radiation.

Radiation injury is termed immediate when manifestations occur within a few months after the onset of overexposure. Late somatic effects occur many months or years after the onset of overexposure and include leukemia, cataracts, cancer, etc. A late effect can develop in a person who has recovered from immediate radiation injury or in a person who has never been sick in spite of protracted exposure. Radiation sickness or skin damage is described as acute when clinical manifestations occur early and do not last longer than 6 months. When symptoms and signs persist beyond 6 months, the condition is chronic. Genetic injury by radiation affects survivors capable of procreation who may, or may not, have experienced observable immediate or late effects. The genetic injury becomes manifested in their descendants by an increased rate of infant mortality and by an increased incidence of hereditary disorders.

2.10. Casualty

The term "casualty" is applied to any individual whose injury or illness is sufficiently serious to require medical care or to cause death. This report is concerned with injury or illness caused by exposure to radiation in an accident, disaster, or a nuclear war.

In such a catastrophe[1] many casualties will be produced by things other than radiation, and there may be many injured by radiation who are not recognized as casualties at the time.

2.11. Recovery

The biological processes that lead to recovery and repair of radiation injury are not yet very well understood. Our knowledge of the recovery process in man is very incomplete; in Section 2.6 are given our best estimates based largely on animal experiments.

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1. Actuaries for life insurance companies define catastrophe as an incident in which five or more lives are lost; a major catastrophe or a disaster is responsible for the death of 100 or more persons.

3. THE EMERGENCY SITUATION

3.1. General

This is the first report by the NCRP on exposure to radiation in an emergency, which is defined operationally (Sec. 2.2) as any situation in which persons could receive an exposure dose in excess of 25 r during a period of 1 week. Previous reports of the NCRP have dealt with controlled—or controllable—situations and the prescription of safeguards and procedures to limit the exposure to radiation to an amount that will not cause appreciable injury.

The basic concept of all radiation protection has recently been stated concisely in Recommendations of the International Commission on Radiation Protection (September 9, 1958):

"(23) Exposure to ionizing radiation can result in injuries that manifest themselves in the exposed individual and in his descendants: these are called somatic and genetic injuries, respectively.

"(24) Late somatic injuries include leukemia and other malignant diseases, impaired fertility, cataracts, and shortening of life. Genetic injuries manifest themselves in the offspring of irradiated individuals, and may not be apparent for many generations. Their detrimental effect can spread throughout a population by mating of exposed individuals with other members of the population.

"(25) The objectives of radiation protection are to prevent or minimize somatic injuries and to minimize the deterioration of the genetic constitution of the population."

Implicit in the circumstances of any emergency is a temporary loss of control over exposure to radiation, so that some or all of the people involved are in danger of receiving doses in excess of permissible limits. At some time after the occurrence of the disaster which caused the radiation emergency, the proper authorities should gain control of the situation and should be able to regulate, to some extent, subsequent exposure of the people in the area. From then until the emergency is terminated, the health and the lives of those at risk depend on decisions made by the officials in charge.

Any decision involving the controllable exposure of an individual to radiation under emergency conditions is intimately related to many factors involving human judgment made under stress. Unfortunately, any decision involving radiation exposure is irrevocable, once the exposure is received. It must be assumed that, while most radiation effects are partially reparable, some may be completely irreversible. Hence, in a given emergency situation, if it is possible to choose between different courses of action—one involving a large exposure and the other a smaller one—the only wise course is to select the one involving the lesser exposure. The acceptance of any radiation exposure is warranted only when there is no practical or reasonable alternative way to achieve the required goal.

The officials in charge of emergency operations must examine any proposed action involving radiation exposure in relation to all other elements of the situation. After an industrial nuclear accident or unexpected fallout from a weapons test, evacuation to an uncontaminated area might be carried out promptly, whereas, during an attack by nuclear weapons, early evacuation of a contaminated area may not be possible or even desirable because of the size and overlap of fallout fields, disruption of communications, uncertainty regarding additional attacks, and other factors. In fact, there may be no uncontaminated region that can be reached without overexposure enroute because of delays or uncertainty in transport. In either type of emergency, conditions will surely occur in which responsible officials must authorize, or order, certain individuals to expose themselves to large doses of radiation to perform high-priority tasks essential for the control of the situation or to prevent additional damage and devastation. In addition to decisions of this type, the responsible official will be expected to issue appropriate directives to regulate the radiation exposure of the people under his authority who are not required to perform special tasks. Decisions must be made regarding the adequacy of shelters; the amount of time that can be spent out of shelter; the time when individual groups can leave shelter permanently to resume their ordinary activities; the potability of water; etc. It is obviously not possible to spell out every such circumstance; and it is certainly not the prerogative of any committee to assign relative values to high-priority tasks, on the one hand, and to the radiation exposure involved in doing so, on the other hand.

3.2. Extent of the Disaster

The worst possible disaster causing a radiation emergency is an attack on the United States with thermonuclear weapons. The Rand civil defense report (1957) predicted the consequences—as an example—of an attack involving 150 target points, 500 weapons, and 1,500 megatons of total yield. The data are shown in Table 3.2a. Depending on the adequacy of civil defense measures, the Rand report estimated that casualties from all causes could total from 5,000,000 to 90,000,000. The difference between the two numbers represents casualties due to unsatisfactory control of exposure to radiation during the postattack period.

The worst conceivable peacetime disaster causing a radiation emergency is the highly unlikely accident to a power reactor with release of half the radioactive material that it contains. The maximum extent of such a disaster is shown in Table 3.2b.

Regardless of the cause of the disaster, it is clear that people who are not inside adequate shelters at the time that fallout commences can receive very large doses of radiation. Thus, even before civil defense officials assume responsibility in a disaster area, some fraction of the people may be severely or mortally in-

TABLE 3.2a. RADIATION DOSE OUTDOORS DUE TO FALLOUT AFTER AN ATTACK WITH THERMONUCLEAR WEAPONS

48-Hour Dose in r*	Area of U.S. Involved, Per Cent†	Minimum Protection Factor for Survival in Shelters‡
0 - 300	30	1 - 2
300 - 750	30	2 - 5
750 - 1,500	25	5 - 10
1,500 - 3,000	10	10 - 20
3,000 - 6,000	4	20 - 40
6,000 - 10,000	1	40 - 65

*Radioactive decay of fallout is so rapid initially that about 90 per cent of the brief, 4-day dose is delivered during the first 48 hours. Note that a 48-hour dose of 6,000 r corresponds to a dose rate of approximately 2,200 r/hr at H + 1 hour, and approximately 11 r/hr, at H + 96 hours (see also Sec. 5.8).

†Estimate based on attack on 150 target points, with 500 bombs and 1,500 megatons of yield.

‡That is, to reduce the 48-hour dose to 200 r or less (see also Secs. 4.9.1 and 5.9a).

Source: Herman Kahn, On Thermonuclear War (Princeton, N.J.: Princeton University Press, 1960).

jured by radiation. It is against this background that the process of decision-making in a radiation emergency must be considered. Recognizing that the purpose of all radiation protection is to minimize injuries, the committee makes the following recommendations:[1]

I. In peacetime emergencies, the objective of radiation protection is the fewest persons exposed, and the least possible exposure to them, and

II. In war emergencies, the objectives are, first, the fewest deaths; second, the fewest requiring medical care; third, the smallest amount of genetic injury; and, fourth, the lowest probability of late somatic effects.

1. Items of particular significance are set out as recommendations of the NCRP.

TABLE 3.2b. POSSIBLE CONSEQUENCES OF A MAJOR ACCIDENT IN A LARGE NUCLEAR POWER PLANT

Consequences	Estimates of Damage*	
	Maximum†	Minimum
Fatal radiation injury	3,400	0
Non-fatal radiation injury	43,000	0
Area contaminated to extent that restrictions are necessary on use of land or crops (sq. miles)	150,000	18
Property damage (thousands of dollars)	7,000,000	500

*Damages calculated for an accident that results in the release of 50 per cent of fission products. The possible consequences vary widely, depending on weather conditions and the temperature of the radioactive material released.

†The worst damage (maximum) could occur only under the adverse combination of several conditions which would exist for not more than 10 per cent of the time and probably much less.

Source: Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants (WASH-740) (USAEC, March, 1957), p. 14.

3.3. The Process of Decision-making

The process of decision-making employs four elements: (1) an input of information, (2) a system for predicting the outcome of any action that may be recommended, (3) a system for assigning values to all such outcomes, and (4) a system of criteria for selecting the appropriate action. In this report, only the first three items are considered in detail, since the criteria for action are the prerogative, as well as the responsibility, of the official in charge. The first three elements require elaboration with respect to a radiation emergency.

(1) Input of information consists of:

(a) Radiological monitoring data, i.e., dose rate outdoors or along any escape route; dose rate in shelters; accumulated exposure dose at any time; predicted accumulated exposure dose at any future time; concentration of radioactive material in air, water, food, and agricultural products; ERD for individuals and population groups at a given time; predicted ERD at a future time; etc.

(b) Size of population at risk; distribution of population in shelters; clinical status of individuals and population groups; medical facilities; resources for evacuation; domestic animals at risk; agricultural crops at risk; requirements for damage control; economic requirements; military requirements; etc.

(2) System for predicting the outcome of any recommended action consists of a schedule—or a series of schedules (Secs. 6.4b and 6.5)—listing the consequences of exposure to different amounts of radiation and radioactive material. The basis for prediction is expert opinion on the dose-effect relationship in man and in domestic animals. (How much damage is caused by a specific dose?) The validity of the system depends, first, on the accuracy of estimates of dose and, second, on the probability that the predicted radiation damage will occur. The term recommended action means a planned, authorized, or required exposure to radiation or radioactive material in excess of permissible limits and in addition to the dose already received. The predicted outcome (e.g., radiation sickness, skin burn, etc.) is understood to be the result of the total exposure during the emergency situation—the authorized dose, plus however much was unavoidable or accidental. The important factors in the development of such a system include the following:

(a) The relation between either brief exposure dose or ERD and acute radiation sickness and the late effects of radiation injury; the relation between skin contamination and cutaneous radiation injury; the relation between ingestion and inhalation and the deposit in the body of specific radionuclides.

(b) The additive effects in man of radiation injury, epidemic disease, nutritional deprivation, emotional reactions, etc.

(3) System for assigning values to all outcomes. The civil defense commander at every echelon of the system may be expected to conform to national objectives of survival, maintenance of the economy, and reconstruction. The characteristics of the medical effects of radiation, which are described in Chapter 6, however, create contingencies in decision-making that either do not occur or are not recognized in the case of other agents (e.g., blast, missiles, fire, etc.) capable of causing casualties in a nuclear war. These contingencies are, first, the prospect of genetic injury to the descendants of the survivors and, second, the late somatic effects on individuals. In disasters that do not involve radiation—such as a conventional military attack on a city or an earthquake—there is little difficulty in assigning values to the outcomes of decisions that expose certain people (rescue workers, firemen, etc.) to the risk of injury or death. Similarly, it is customary for decision-makers to try to minimize the risk of injury and hardship to children, pregnant women, the sick and wounded, and the aged. The unique contingencies that must be considered when radiation is included among the perils of a disaster affect not only children and pregnant women but also the majority of the able-bodied men and women who bear the brunt of maintaining the economy and reconstruction.

To the extent that it is possible to do so in a radiation emergency, all decisions involving additional exposure should conform to a scale of values ranging from the least to the most desirable outcome, as follows:

(1) Death due to immediate effects of radiation
(2) Immediate radiation sickness or injury to the skin severe enough to require medical care and to prevent the casualty from working
(3) In the case of people capable of procreation—that is, generally less than 40 years old—no immediate radiation injury but the definite probability of genetic injury
(4) No immediate injury, but the definite probability of late somatic effects
(5) No immediate injury and little or no probability of genetic injury or late somatic effects

Ordinarily, it is the prerogative of the decision-maker to develop a system for assigning values to all possible outcomes of the actions that are taken. In the case of radiation emergencies, however, the NCRP is obliged to make recommendations concerning the risk of genetic injury that are consistent with its general philosophy (see Sec. 1.1).

3.4. Predicting the Outcome

The fundamental question that must be answered whenever a decision is required that involves additional exposure is "How much radiation injury will be caused by a specific total accumulated dose?" The degree of confidence with which the outcome can be predicted depends on certain radiological and biological considerations that are discussed in detail in Chapters 5 and 6, respectively. Some general principles, however, deserve attention in this section.

a. Estimates of Dose

The data will be given numerically (e.g., r/hr). They may be raw measurements or extrapolations from measurements, most usefully reduced to values that would obtain at 1 hour or 1 day after the detonation of a nuclear weapon or the accident responsible

for the emergency. Any variations reported should state whether they are based on measured differences or on the performance characteristics of the instruments. For assistance in decision-making, ranges (i.e., estimates of the maximum and minimum) are preferable to single or average values, since an indication of the range will help the responsible official estimate how much risk a given decision entails.

When using estimates of dose to predict the immediate outcome, the committee recommends:

III. Make no allowance for recovery during the first 4 days, but take the accumulated total dose as equivalent to a single dose of equal size, and

IV. Use the equivalent residual dose (ERD) for exposure protracted beyond 4 days.

b. The Population at Risk

Data concerning the population at risk and other items considered as input of information (Sec. 3.2) should be readily available from appropriate official sources. On the basis of the results of experiments with animals, it is likely that people vary somewhat in their susceptibility to the effects of radiation, depending on age, sex, race, and general health. However, there is no information (in 1961) on the extent to which these factors modify the outcome of a given dose of radiation. In fact, the statistical study of the Japanese atomic bomb casualties failed to disclose any significant difference that could be attributed to age or sex. Accordingly, the committee recommends:

V. The entire population be considered equally susceptible to the effects of radiation.

c. Distinction between Injuries

It should be clearly understood that Recommendation V does not mean that no attempt should be made to limit the exposure of certain groups of people if it is possible to do so. When the number involved in a radiation emergency is small (several thousand, for example), it should be feasible to control the exposure of the vulnerable section of the population—namely, people under age 40—to minimize the risk of genetic injury. When the number of people is very large—as in the case of an attack with nuclear weapons—it may not always be practical to identify the vulnerable individuals and make special provisions for them, however commendable such a policy may be. At present, the age group 18-40 comprises about one-third of the population. Following a nuclear attack on the United States, the decision regarding the extent to which exposure of this group should be limited ought to be made at the national level.

People who become casualties from overexposure to gamma radiation or because of beta-ray burns of the skin need medical care and hospitalization. There is no evidence at present to suggest that the medical requirements of radiation casualties are substantially different—in terms of time and effort—than the requirements of casualties due to other causes, or the needs of people with the ordinary run of diseases and injuries. For this reason, the committee recommends:

VI. No administrative distinctions should be made between injuries caused by radiation and other casualty-producing agents.

d. The Probable Outcome

The consequences of exposure greatly in excess of normal permissible limits are discussed in Chapter 6. The term "clinical radiation injury" (Sec. 6.4) comprises at least five categories of sickness due to exposure of the whole body to external or internal γ-radiation; at least four categories of skin damage due to β-radiation; and several types of internal injury due to selective de-

posit of radioisotopes. In every instance it is possible to ascribe a particular effect to a range of doses, sometimes on the basis of experience and sometimes by extrapolation from animal experiments. Attempts have been made by others to assign a numerical probability for the occurrence of each particular outcome following exposure to a specified dose or range of doses. The committee does not have sufficient confidence in any such system to recommend its use in an emergency. Furthermore, so many combinations of exposure and effects are possible that decision-making on such a basis becomes difficult, if not impossible. In order to simplify the situation, the committee recommends:

VII. The categories of outcome of exposure to radiation be limited to:

(1) Medical care not required
(2) Medical care required during the emergency period or subsequently (except that late effects are not considered)
(3) Death

In accordance with Recommendation VI, no distinction should be made between the various types of radiation injury—whole-body, skin, or internal. At any time that an administrative decision is required regarding additional exposure to radiation—whether in the case of an individual or of a group—four questions must be answered before a proper directive can be issued:

(1) What is the estimated dose (ERD, skin dose, or body burden) that the individual(s) has (have) received up to this time?

(2) Is the physical (or clinical) condition of the individual(s) consistent with this estimate of dose?

(3) What is the additional dose (ERD, skin dose, or body burden) that the individual(s) will probably receive as a result of the proposed action?

(4) What will be the physical (or clinical) condition of the in-

dividual(s) after this additional exposure?

It is evident that these four factors require evaluation, regardless of whether the additional exposure involves a radiation field, radioactive dust, or contaminated water and food.

4. SUMMARY OF GUIDELINES FOR MAKING ADMINISTRATIVE DECISIONS IN A RADIATION EMERGENCY

4.1. General Principles

(1) The objective of all radiation protection is to minimize injuries (Sec. 3.1).

(2) In peacetime emergencies, the objective of radiation protection is the fewest persons exposed and the least possible exposure to them (Secs. 3.2 and 3.3).

(3) In war emergencies, the objectives are, first, the fewest deaths; second, the fewest requiring medical care; third, the smallest amount of genetic injury; and, fourth, the least probability of late somatic effects (Secs. 3.2 and 3.3).

(4) For practical purposes, assume that the entire population is equally susceptible to the effects of radiation (Sec. 3.4).

(5) People should remain in whatever shelters are immediately available until the radiological situation is evaluated (Sec. 1.2).

(6) Casualties due to radiation are the same, administratively, as casualties due to blast, fire, toxic chemicals, etc. (Sec. 3.4).

4.2. System for Predicting Immediate Outcome of Exposure

(1) Make no allowance for recovery during the first 4 days but take the accumulated total dose as equivalent to a single dose of equal size (Sec. 3.4).

(2) Use the equivalent residual dose (ERD) for exposure protracted beyond 4 days (Sec. 3.4).

(3) When neither the brief dose nor the ERD exceeds 200 r, the majority of people will not require medical care (Secs. 3.4

and 6.4, Table 6.4).

(4) When either the brief dose or the ERD is between 200 and 600 r, the majority will require medical care and about half may die eventually (Secs. 3.4, 6.4, Table 6.4).

(5) When the dose is more than 600 r, the majority will die (Secs. 3.4, 6.4, Table 6.4).

(6) The median lethal γ-ray dose (brief exposure or single dose) for man is 450 r (Secs. 6.3, 6.5).

(7) Skin injury is possible when the concentration of fission products on skin exceeds 2 microcuries per square centimeter ($\mu c/cm^2$) (Sec. 5.10).

(8) When the β-ray dose to the skin is less than 1,000 rads, the majority of people will not require medical care (Sec. 6.6 and Appendix II).

(9) When the β-ray dose is more than 2,000 rads, the majority will require medical care.

(10) The reliability of any prediction of radiation injury cannot be any greater than the reliability of the estimate of dose (Sec. 5.5).

(11) Any prediction of the number of casualties may be incorrect by as much as ±25 per cent (Sec. 6.3).

(12) The possibility of genetic injury and of late effects of radiation should not be the principal determining factor when making decisions during an emergency [Secs. 6.4b(6) and 6.4b(7)].

(13) Decisions regarding work capacity should be based on medical evidence of fitness and not on estimates of exposure dose (Sec. 6.8).

4.3. Reliability of Physical Estimates of Dose under Emergency Conditions

The effect of an actual dose to an individual depends on many biological factors that cannot be precisely evaluated and must, of necessity, be disregarded or the planning problem becomes unmanageable. For practical purposes, the accuracy of estimates of

dose should be considered to be the same as the accuracy of the instrumental measurement under the following conditions:

(1) When dose is measured by personal dosimeters, e.g., pocket ionization chambers, etc., the error, even under ideal conditions, may be as great as ±25 per cent of the true value (Sec. 5.9b).

(2) When dose is calculated from dose rate measured by survey meters, the error may be as great as ± 35 per cent (Sec. 5.9b).

(3) When dose is calculated on the basis of area dose rates by means of a map on which isodose lines have been drawn, the error may be as great as ± 50 per cent (Sec. 5.9b).

(4) When dose in the non-lethal range is estimated on the basis of the severity of radiation sickness, the error may be at least ±25 per cent (Sec. 6.4c).

5. RADIOLOGICAL CONSIDERATIONS

5.1. General

A radiation emergency can occur in any of the situations listed in Table 2.2 (p. 9). In each case there is the possibility of human casualties, loss of livestock, and damage to agricultural crops, depending on the location and the extent of the area involved. In addition to variations due to geographical factors, emergencies differ with respect to the extent and the nature of the radiation hazard. The difference between the problems in two catastrophes may be so great that an action which was proper in the first would be disastrous in the second. It is particularly important to realize that policies designed for an emergency due to radioactive fallout after the detonation of a nuclear weapon are not always applicable to the "accident" situations noted in Table 2.2. The difference between radiation emergencies depends on the physical and chemical characteristics of the radioactive material, the circumstances of its release, and the amount available. In the final analysis, the decisions that must be made in an emergency depend on correct interpretation of the radiological situation. In this chapter a number of miscellaneous factors that are important for an appreciation of the radiological situation are explained and discussed.

5.2 Radioactive Material

Radioactive material may be a single radioisotope, a mixture of radioisotopes, fission products (FP),[1] or a mixture of fission products and debris in which radioactivity has been induced by neutrons released in a nuclear explosion. It may be dispersed as a radioactive cloud, consisting of volatile substances and particles ranging in size from submicroscopic to visible. Particulate material is ultimately deposited as radioactive fallout, the distribution of which depends principally on the prevailing weather conditions. Radioactive material may emit any or all of the three types of nuclear radiations—gamma rays, beta rays, alpha rays; this report deals only with the first two. The radioactive material may be soluble or insoluble, and, in addition to its radioactivity, it may be associated with toxic chemicals.

5.3. Radioactive Cloud

The mushroom formed after the detonation of a nuclear weapon is an explosion-debris cloud that is radioactive. After an air burst or a surface burst, the cloud rises rapidly, and radiation emanating directly from radioactive material in the cloud poses little danger to persons on the ground who have survived the blast. Underwater and underground bursts produce explosion-debris clouds that may remain close to the ground and contain sufficient radioactive material to cause serious injury to people and animals. Some types of reactor accidents may release FP as a cloud in which radioactive material is sufficiently concentrated to cause fatal radiation injury. Explosions—from any cause—in a reactor, a chemical processing plant, or a waste-disposal facility can produce clouds consisting of debris, radioactive material, and toxic chemicals. To date (1961), experience with radioactive clouds—other than those due to nuclear weapons—is limited to small releases, or "puffs," of FP in reactor accidents. In most such cases, serious contamination has been limited to small areas immediately surrounding the facility.

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1. Fission products are termed "young" or "fresh" when they are produced in a nuclear explosion or a critical assembly accident. The FP released from a reactor that has been in operation for several months or longer are mostly "old." It is important to distinguish between ages because the decay rates will be very different.

In estimating the dose received by a person exposed to a radioactive cloud from a reactor accident, it is convenient to imagine that the individual is engulfed in an infinite volume of radioactive gas or aerosol for a time long enough (i.e., minutes) that the air in his lungs comes into equilibrium with the air of the cloud. Some fraction of the FP inhaled is deposited in the lungs, and a portion of this remains in the body. The person, therefore, receives a brief external dose to the whole body, plus protracted radiation (γ, β, and α) to the lungs and other organs due to internally deposited material. The size of the combined exposure is determined by the amount of FP in the cloud and the time during which the air is contaminated. Exposure is expressed as curie-seconds per cubic meter of air (c-sec/m^3).[2]

5.4. Radioactive Fallout

Particulate material in a radioactive cloud is transferred to ground surfaces, people, buildings, and vegetation by "fallout," "washout," and "rainout." It is customary to use fallout as a collective term for all the processes involved in the contamination of ground surfaces, etc. The word is also used to signify the particulate radioactive material deposited on the ground, skin, etc., from the atmosphere. The extent and nature of fallout can range between wide extremes. The actual behavior will be determined by a combination of circumstances associated with the explosion and with geographical and meteorological conditions. The source of the radioactivity may be the result of an industrial accident or of the detonation of a nuclear weapon. With few exceptions, contamination of areas larger than a single building will be caused by fallout of material dispersed in the atmosphere. It should be understood that

2. 1 m^3 = 35 cubic feet; the expression c-sec/m^3 implies that it makes no difference whether the exposure lasts for 1 second in a cloud containing 100 c/m^3, or 100 seconds in a cloud containing 1 c/m^3, etc.

fallout is a gradual phenomenon extending over a period of time and continuing after the cloud is no longer visible.

5.5. Estimation of Dose Due to Fallout

In estimating the dose received by a person from fallout, it is convenient—but not strictly accurate—to assume that radioactive contamination is deposited uniformly over the ground and other horizontal surfaces. The dose rate in the radiation field is measured conventionally 3 feet above the surface and is reported in r/hr. Ordinarily, the radiation field is reported as of a given time or is frequently corrected to a conventional reference time, H + 1 hour, which means 1 hour after the event responsible for the emergency. The amount of radioactive material per unit of surface is referred to as the contamination or, more properly, as the contamination density and is reported as curies per square meter (c/m^2), or megacuries per square mile (Mc/mi^2). One curie per square meter of mixed fission products will give a gamma-radiation field of between 10 and 20 r/hr. A surface burst of a megaton thermonuclear weapon is expected to produce an extensive fallout field, which in places may exceed 3000 r/hr at H + 1 hour.

People and animals in a fallout field are literally immersed in a "crossfire" of radiation, consisting of a mixture of γ- and β-rays. The β-ray component is contributed by fallout adhering to skin and clothing, as well as by material deposited on the ground. In most situations, it is stated that external γ-radiation, because of its greater penetrating power, is the principal hazard of fallout. It is quite possible, however, to have casualties and deaths due to radioactive dust blown into "safe" shelters and buildings, the ventilation of which is either inadequate or improperly operated (Sec. 5.3).

5.6. Radioactive Contamination of Skin

Fission products adhering to the skin irradiate it with both beta and gamma rays. The beta rays give up their energy in the first few millimeters and so produce a much larger skin dose than the gamma rays, which are very much more penetrating. The beta rays can produce a serious burn without the gamma rays reaching a lethal dose. The unit of contamination density on the skin is microcuries per square centimeter ($\mu c/cm^2$).[3]

The ability of beta radiation to cause visible damage to skin depends on a complex relationship between average energy (roughly, the penetrating power of the rays), contamination density, and duration of contact. Contact is very important, and one of the principal facts learned from experience with fallout is that recognizable β-ray damage to skin has occurred principally on the areas of the body where the radioactive material actually remained in contact with the skin. When skin contamination is caused by weapons fallout, a factor tending to reduce the exposure is the relative insolubility of the material. Most studies of particulate fallout indicate that less than 10 per cent is readily soluble in water. Even though the particles may adhere to the oily surface of the skin, they are not absorbed, and decontamination can be relatively simple and effective.

5.7. Radiation from Material Deposited Internally

Inhalation and ingestion are the principal means for the entry of radioactive material into the body. As long as any remains, the body is exposed to internal radiation. There is an important difference between external and internal irradiation. External irradiation ceases after the radioactive cloud has passed or after the person has left the radiation field. The radiation injury that has already occurred may, of course, develop later into radiation sickness, even though there is no further addition to the accumulated exposure dose. Internally deposited material continues to radiate,

3. The relationship between this unit and the ones used for contamination of land surfaces is

$$2.6\ Mc/mi^2 = 1.0\ c/m^2 = 100\ \mu c/cm^2.$$

however, and the accumulated dose increases until excretion or radioactive decay removes the material. The significance of internally deposited material is illustrated in Table 5.7a, where it can be seen that, after exposure to air-borne "old" FP from a reactor, the radiation dose to individual organs may be greater than

TABLE 5.7a. EXPECTED EFFECTS OF EXPOSURE TO 1.0 $c\text{-}sec/m^3$ IN A RADIOACTIVE CLOUD CONTAINING "OLD" MIXED FISSION PRODUCTS*

External γ-dose	0.28 r†
Lung β-dose	0.24 r
Bone dose from $Sr^{89} + Sr^{90}$	0.69 r
Bone dose from $Ce^{144} + Pr^{144}$	0.53 r
Thyroid dose from radioisotopes of iodine	0.25 r
Dose to intestinal tract	0.28 r

*Source: Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants (WASH-740) (USAEC, March, 1957), Table 1, Appendix D. Note that 1 cubic meter is the volume of air breathed by an average man in 75 minutes. When the time of exposure to the cloud is long enough—in excess of 30 seconds—for the air in the lungs to equilibrate with the air in the cloud, the relationship $c\text{-}sec/m^3$ is the proper way to express the exposure.

†These doses could be received from breathing air containing $0.22\ mc/m^3$ for 75 minutes or from $16\ mc/m^3$ for 1 minute.

the external γ-ray dose. A different situation results from exposure to particulate fallout from a nuclear explosion and involving only "young" FP. The data in Table 5.7b were obtained from studies of the Marshallese who remained on Rongelap Island for nearly 2 days in a fallout field, drinking contaminated water and eating contaminated food. According to the best estimates, external γ-ray dose was many times greater than the internal dose to individual organs. The contamination density of this fallout was between 1.5 and 3.0 c/m^2. Local meteorological conditions—e.g., trade

TABLE 5.7b. EFFECTS OF FALLOUT ON MARSHALL ISLANDERS*

External γ-dose 175 r

Internal dose - about 10 r

Sources of Internal Dose		Maximum Permissible Body Burden (μc)†	
Isotope	Body Burden‡ (μc)	Total Body	Critical Organ
Strontium-89 ·	22.0	40	(Bone) 4.0
Iodine-131 · · ·	11.2	50	(Thyroid) 0.7
Barium-140 · ·	2.7	9	(Bone) 4.0
Others · · · · ·	<5.0		

*Source: Some Effects of Ionizing Radiation on Human Beings (TID 5358) (USAEC, 1956).

†For adults occupationally exposed, see NCRP-NBS Handbook 69.

‡Estimated activity at 1 day after detonation; the values listed are the upper limit of the range of observed values in each case.

winds, high humidity, etc.—were responsible for the small internal radiation exposure due to this accident.

a. Inhalation

Inhalation occurs when the inspired air contains radioactive gas or aerosol. Approximately 25 per cent of the inhaled material is retained, dissolved in the secretions of the respiratory tract. The rest is breathed out again or spit out. Some of the material deposited in the lung is later coughed up and swallowed. Readily soluble material is absorbed from the lungs and the bowel. Insoluble material may be eliminated slowly or remain in the lungs for long periods of time.

b. Ingestion

Ingestion of radioactive material results from drinking contaminated water, eating contaminated food, or swallowing mucus contaminated by aerosol from the lungs or nose. While in the stomach or the bowel, it irradiates the mucosal surfaces. After absorption, it goes to the various organs and irradiates them. The water supply is generally considered an important source of internal hazard for the whole population in an emergency due to fallout, while for domestic animals the food supply may be more important.

It is difficult to predict the extent of contamination of water on the basis of the contamination density of the land adjacent to surface water used for drinking. Aerial monitoring of large bodies of water—such as reservoirs—can be used to evaluate its contamination density. When the dose rate at the surface is 1 r/hr, the surface water contains about 1 curie per cubic yard.[4] Many factors operate to remove radioactive material from drinking-water systems, and it is not possible to generalize on the extent to which they may be effective. Actual measurement of radioactivity of water for drinking should be carried out if possible.

5.8. Rate of Decay

The rate of decay of radioactive material is of great importance in any kind of emergency situation. Individual radioisotopes decay in an exponential fashion, which means that half the remaining radioactivity is emitted in equal, successive periods of time. The decay rate of a radionuclide is referred to as its "half-life," the units of which may be seconds, hours, days, etc. Mixtures of many radionuclides (such as FP), the half-lives of which vary greatly, behave differently. As the mixture "ages," the short-lived material disappears, with the result that the initially rapid decay

4. 1 c/yd^3 = 5 mc/gal = 1.3 μc/cm^3. The inhabitants of Rongelap Island (see Table 5.7b) drank cistern water, the activity of which must have been at least 0.2 μc/cm^3 when fallout was completed at about H + 10 hours.

TABLE 5.8a. INFLUENCE OF RADIOACTIVE DECAY ON DOSE RATE OF A RADIATION FIELD CONTAMINATED WITH FISSION PRODUCTS, OR IODINE-131

Time of Measurements*	Per Cent of 1-Hour Dose Rate Expected at Later Times		
	Young FP†	Old FP‡	I^{131}§
H + 1 hour	100	100	100
H + 10 hours	6.3	64	96
H + 100 hours (approx. 4 days)	0.4	40	76
H + 1,000 hours (approx. 40 days)	0.025	25	3

*H + 1 hour is the conventional reference time used in reporting fallout.

†The rapid decay factor, $t^{-1.2}$, describes the behavior of young FP in fallout from a nuclear weapon and also of young FP released by a critical assembly accident in a nuclear reactor.

‡The slow decay factor, $t^{-0.2}$, describes the behavior of old FP released from a nuclear reactor that has been in stable operation for 3-6 months or longer.

§The decay rate, or half-life, of I^{131} is 8 days.

rate becomes progressively slower. Fission products from a nuclear explosion decay at the most rapid rate for the first few months after the event. Volatile FP from a power reactor that has been in stable operation for 3 months or longer decay at an intermediate rate, and the entire FP mixture released through accident from such a power reactor has a slow decay rate.[5] The practical

5. Fission products from a nuclear explosion decay at the most rapid rate: the resulting gamma-ray dose rate follows approximately the relationship $t^{-1.2}$, for the first few months after the event (t stands for "time" in some arbitrary units such as days, etc.). Volatile FP from a power reactor that has been in stable operation for 3 months or longer decay at an intermediate rate, approximately $t^{-0.8}$; and the entire FP mixture released from such a power reactor has a slow decay rate, about $t^{-0.2}$.

significance of differences in the decay process as the determinant of the decrease in the dose rate of a radiation field with the passage of time is demonstrated in Table 5.8a. Data on radioiodine (I^{131}) are included as an example of the behavior of a single isotope, with a half-life of 8 days. The influence of the decay rate on the accumulated exposure dose is of the utmost importance, a fact that is clearly shown in Table 5.8b.

TABLE 5.8b. INFLUENCE OF RADIOACTIVE DECAY ON ACCUMULATED DOSE FROM FISSION PRODUCTS IN A RADIATION FIELD*

Duration of Exposure in Radiation Field†	Accumulated Total Dose in r	
	Young FP from a Nuclear Weapon‡	Old FP from a Power Reactor§
1 day	24	150
1 week	32	740
1 month	37	2,400
1 year	42	17,800

*The accumulated doses are calculated only on the basis of radioactive decay. No allowance is made for the influence of weather and other natural factors which are known to occur and which operate to reduce the size of the accumulated dose with the passage of time.

†Duration of exposure following H + 1 hour, when the dose rate was 10 r/hr.

‡Based on rapid decay factor: $t^{-1.2}$.

§Based on slow decay factor: $t^{-0.2}$.

Note.—For the same initial contamination density, it is obvious that old FP are a much more serious hazard than young FP.

5.9. Gamma Radiation

It is common knowledge that γ-rays are able to penetrate the human body (and other objects or material) in the same fashion as do X-rays. The penetrating power of a radiation depends on its energy, a quantity that is expressed in units of electron volts.[6] Gamma rays are absorbed (or attenuated) to some extent in the course of their passage through any material. As a rough rule, it may be said that the absorption of high-energy gamma radiation is dependent on the mass (e.g., volume x density) of material that intervenes between the source of the rays and the point of observation. This means that it would require a greater thickness of a substance of low density—e.g., water—than one of high density—e.g., iron—to attenuate the radiations by a specified amount. Strictly speaking, it is not possible to absorb gamma rays completely. Nevertheless, if a sufficient thickness of matter is interposed between the source, such as an exploding nuclear bomb or a radiation field, and an individual, the exposure dose can be reduced to negligible proportions.

The effectiveness of a given material in decreasing the radiation intensity can be conveniently represented by a quantity called the half-value layer (HVL). This is the thickness of the particular material which absorbs half the radiation falling upon it. Thus, if a person is in a position where the exposure dose would be 400 r with no shielding, the introduction of one half-value layer[7] of any material would decrease the dose to (approximately) 200 r. The addition of another half-value layer would again halve the dose, i.e., to (approximately) 100 r, and so on. The chief materials likely to be available for shielding—which is to say for shelters—in a radiation emergency are steel, concrete, earth, and wood. The approximate half-value layer of these substances for the gamma radiations of nuclear weapons are given in Table 5.9a. It is apparent from this that the gamma component of the initial nuclear radiation (i.e., that emitted at the time of explosion) is more energetic than the gamma component of the residual nuclear radiation (i.e., gamma rays from the older fission products and radionuclides produced by neutron capture) responsible for a fallout field. As indicated by the results in the fourth and sixth columns of Table 5.9a, the product of density times the half-value layer thickness depends on the quality of radiation but is roughly the same when all five materials are exposed to the same source.

TABLE 5.9a. APPROXIMATE HALF-VALUE LAYERS OF MATERIAL FOR GAMMA RAYS*

Material	Density (lb/ft³)	Initial Nuclear Radiation		Fallout Radiation	
		Half-Value Layer (Inches)	Product	Half-Value Layer (Inches)	Product
Steel	490	1.5	735	0.7	343
Concrete .	144	6.0	864	2.2	317
Earth . . .	100	7.5	750	3.3	330
Water . . .	62	13.0	811	4.8	300
Wood . . .	34	23.0	782	8.8	300

*Source: The Effects of Nuclear Weapons (Washington: Department of the Army, 1957), Tables 8.44 and 9.35.

As one moves away from a point source of gamma radiation, the intensity (or the dose rate) decreases according to the inverse-square law. This means that when the distance from the point source is doubled, the intensity is reduced to one-fourth (that is, $1 \div 2^2$) of the value at the original position. Tripling the distance reduces the dose to one-ninth, and so on.

6. The usual abbreviations are: one million electron volts = 1 Mev; one thousand electron volts = 1 kev.

7. The term "half-value layer" (HVL) is also used to describe the quality, or the penetrating power, of γ-rays and X-rays. In this sense, HVL means "radiation of such a quality that the intensity is reduced to one-half by that thickness of material." The measuring material may be aluminum, copper, lead, etc., and the (average) energy or quality is specified as so many millimeters of the material mentioned.

a. Protection Factor

Protection from the gamma radiation of fallout may be achieved in three ways. One method is to place a barrier between the fallout field and the individual. This is termed "barrier shielding." The second method is to increase the distance of the individual from the fallout field. This is termed "geometry shielding." The third method is to decrease the duration of exposure. In most situations, protection is provided by a combination of barrier and geometry shielding. The term "protection factor" is used to express the relative reduction in the amount of radiation that would be received by a person in a protected location compared with the amount he would receive if he were unprotected. The protection factors that might be expected inside various common structures are listed in Table 5.9b. The analysis of the protection afforded by these structures includes the influence of barrier shielding (e.g., walls, floors, ceilings, etc.) and of geom-

Notes to Table 5.9b

*The table relates shelter categories to corresponding protection factors. It is intended to provide (1) a general idea of the relative amounts of protection afforded by common types of buildings and (2) a preliminary estimate of potential shelter areas for survey-programing purposes. These protection factors may be conservative in many cases, since they are based on isolated structures. For example, in the case of a building surrounded by taller buildings, the protection factor might be increased sufficiently to raise it to a higher category. In any case, on-site examination and practical judgment must be used before a protection factor is assigned to any given structure.

†This term expresses the relative reduction in the amount of radiation that would be received by a person in a protected location, compared with the amount he would receive if he were unprotected.

‡These examples refer to isolated structures.

§For the purposes of this example, "high-rise" buildings are those greater than about 10 stories—multistory, 3-10 floors.

Source: Fallout Shelter Surveys: Guide for Architects and Engineers (NP-10-2 National Plan Appendix Series) (Office of Civil and Defense Mobilization, May, 1960).

TABLE 5.9b. PROTECTION FACTOR FOR GAMMA RADIATION FROM FALLOUT*

Shelter Category	Protection Factor†	Common Examples‡
A.	1,000 or greater (10 HVL or more)	OCDM underground shelters Subbasements of multistory buildings Underground installations (mines, tunnels, etc.)
B.	250 - 1,000 (8 to 10 HVL)	OCDM basement fallout shelters (heavy masonry residences) Basements (without exposed walls) of multistory buildings Central areas of upper floors (excluding top 3 floors) of high-rise§ buildings with concrete floors and heavy exterior walls
C.	50 - 250 (5-1/2 to 8 HVL)	OCDM basement fallout shelters (frame and brick-veneer residences) Central areas of basements (with partially exposed walls) of multistory buildings Central areas of upper floors (excluding top floor) of multistory buildings with concrete floors and heavy exterior walls
D.	10 - 50 (3-1/3 to 5-1/2 HVL)	Basements (without exposed walls) of small 1- or 2-story buildings Central areas of upper floors (excluding top floor) of multistory buildings with light floors and exterior walls
E.	2 - 10 (1 to 3-1/3 HVL)	Basements (partially exposed) of small 1- or 2-story buildings Central areas on ground floors in 1- or 2-story buildings with heavy masonry walls
F.	2 or less (less than 1 HVL)	Above-ground areas of light residential structures

etry shielding (e.g., distance from fallout on the ground or on the roof, windows, etc.). A fifty-fold reduction of radiation dose or dose rate (that is, a protection factor of 50 or more) would make survival possible in some areas of heavy fallout such as those noted in Table 3.2a.

b. Accuracy of Gamma-Radiation Dosimetry

Postattack reports of dose received may be based on direct measurements—the readings of personal dosimeters such as pocket ionization chambers, etc.—or they may be calculated from area-survey data. With the latter, the values for dose rate can be better measured by monitoring the area of interest, or the values may be taken from a map of the locality on which isodose lines have been drawn as a result of a general area survey. The report of the additional dose that an action will entail is necessarily a predicted dose based on area-survey data and on assumptions regarding shielding, protection factors, decay rate, etc. Practically, in an emergency it is unlikely that a thoroughly accurate statement of dose can be made, and the best that can be done is to use preassigned values for the uncertainty of each kind of estimate. The instruments likely to be used in an emergency are survey meters (dose-rate meters) and pocket dosimeters that record the total dose. The accuracy specifications for pocket dosimeters (OCDM) is reported to be plus or minus 20 per cent of the true dose. To this variation must be added the effect of such factors as the direction from which the radiation is coming, the attenuation by body absorption and scattering, and the relationship of surface dose to whole-body dose. Uncertainties, other than those of instrumental nature, can be large in comparison with those based on physical measurement, yet there is no reliable means of evaluating them. This is so even under well-managed laboratory or industrial conditions. However arbitrary it may seem, such uncertainties when spread over a large number of people are assumed to balance out. Also, in the absence of any better information, and in an attempt to give some perspective to the uncertainty, it is assumed that evaluations based

on instrumental considerations are valid. The committee recommends:

VIII. Estimates of accumulated exposure dose based on pocket dosimeter readings should be assigned an uncertainty of ± 25 per cent.

A good survey meter under ideal conditions can measure dose rate with an accuracy ranging from ± 5 to ± 25 per cent, depending on a number of circumstances. Even with the most accurate meter, however, local variations in a radiation field may be so great that the readings reported can deviate by more than ± 25 per cent from the average value. The committee recommends:

IX. Estimates of dose based on actual area monitoring reports should be assigned an uncertainty of ± 35 per cent.

In postattack situations, estimates of dose may be made by using maps on which isodose contour lines have been drawn. The committee recommends:

X. Estimates of dose from maps should be assigned an uncertainty of ± 50 per cent.

Since predicted dose is necessarily based on monitoring or survey data and on calculations of protection factors, the committee recommends:

XI. Predictions of dose should be assigned an uncertainty of ± 35 per cent or ± 50 per cent, depending on the type of survey information available.

It is obvious that at least the same degree of uncertainty that is assigned to an accumulated exposure dose, or to a predicted exposure dose, should also be assigned to the ERD derived therefrom. The assumptions used in calculating ERD (regarding rate of recovery and irreparable injury) are partially theoretical and may be in error to an unknown extent. Furthermore, there is no way of knowing whether the radiological errors will offset the biological ones or add to them. In spite of this, the committee recommends:

XII. <u>All estimates of ERD should be assigned the same per cent uncertainty as the accumulated exposure doses on which they are based.</u>

The amount of error inherent in any estimate of γ-radiation has important consequences in relation to the process of decision-making. A given measurement of radiation (R) may be simply reported as read and then have assigned to it the appropriate range of uncertainty (see Recommendation IX above). Decisions made on the basis of such a measurement will then depend on the degree of credence given the measurement and on the importance of the mission that will necessitate having to submit persons to such a dose.

For a highly important mission, the official may feel the necessity of carrying it out on the basis of the minimum value, R - 35 per cent; the consequent risk to the persons exposed is a maximum, within the concepts used here. A low-priority mission should probably be based on the maximum value, R + 35 per cent; the consequent risk is minimum. For "average" missions, the average dose value, R, might be used. It is obvious that there can be no simple rules for such decision actions, and the better trained the responsible officer, the less the uncertainty in the risks resulting from his judgment.

In peacetime disasters where good instrumentation and trained individuals will presumably be available, the process of decision-making can be considerably tightened. As far as possible, the allowance of large doses for critical situations should be permitted only when the instrumentation and measurement capability are relatively highly sophisticated.

It should be obvious to everyone that the outcome of any action based on an estimate of dose cannot be expected to have a higher degree of certainty than that of the information used to make the decision.

5.10. Beta-Radiation Dosimetry

Beta rays consist of negatively charged particles—electrons—the energy of which varies from a few thousand to a few million electron volts. The range of a β-particle in air depends on its energy and may exceed 10 feet before it is absorbed. The range is shorter in more dense media, and the average net distance that a particle of given energy can travel in water, wood, or body tissue is roughly 1/800 of that in air. Persons in the interior of a house are thus protected from β-radiation emitted by material deposited outside. It appears that even a moderate thickness of clothing provides substantial attenuation of β-radiation, the exact amount varying with the weight (thickness) and the number of layers.

Beta-radiation injury to the skin may cause casualties in any type of emergency that involves FP or the release of β-emitting radioisotopes. Measurements of dose and the evaluation of hazards are quite difficult because of the complicated interrelation of such factors as average energy, contamination density, area of contamination, the period of time during which the skin is exposed, and the additive effect of gamma radiation. An example of the difference between the surface doses of different β-emitters required to produce recognizable injury to pig skin is given in Table 5.10. The surface dose, as reported, varied from 20,000 to 1,500 r,[8] depending on the average energy; but the dose at a depth of 0.1 mm was

8. The unit of dose used at the time of the report quoted in Table 5.10 was the "roentgen equivalent physical"—rep. Absorbed dose is now given in rads. To the accuracy given in Table 5.10, 1 rep = 1 rad. However, in this report the unit of radiation dose is the roentgen (r) (see Sec. 2.3).

TABLE 5.10. AMOUNT OF BETA RADIATION REQUIRED TO PRODUCE RECOGNIZABLE INJURY TO THE SKIN OF THE PIG*

Isotope	Maximum Energy (Mev)	Surface Dose Required (rep)†	Estimated Dose within Skin (rep)†
Sulfur-35 . . .	0.17	20,000	1,200
Cobalt-60 . . .	0.31	4,000	1,600
Cesium-137. .	0.52	2,000	1,700
Yttrium-91 . .	1.54	1,500	1,200

*Based on report by A. R. Moritz and F. W. Henriques, Lab. Invest., 2:167, 1952 (No. 2).

†Dose estimated at a depth of 0.1 mm (about 1/300 inch) where injury to living cells of the skin causes a "burn." The unit of dose used at the time of the report quoted was the roentgen equivalent physical—rep. Absorbed dose is now given in rads. To the accuracy given here 1 rep = 1 rad. However, in this report the unit of radiation dose is the roentgen (r) (see Sec. 2.3).

approximately the same in each case: 1,400 ± 300 r. The beta exposure from mixed fission products approximates that from yttrium-91 (in Table 5.10) or phosphorus-32.

From a practical standpoint, it is desirable to predict the risk of beta-ray injury from data that are most likely to be readily available in an emergency—namely, the dose rate measured above the ground level out of doors. On the basis of some limited experience resulting from weapons tests, one may take as a very rough approximation for short periods of time (e.g., days) that the beta-ray dose to the skin (from fallout material in direct contact with the skin) is at least 50 times the gamma-ray dose measured in roentgens at a point about 3 feet above the surface of the ground. (For some further empirical relationship between contamination and skin dose see Appendix III.)

When this method of estimating beta-radiation dose is checked against field observations made on the Marshall Islanders, it appears that the predicted skin dose was 6 or 7 times larger than was actually the case. The factors responsible for the discrepancy are not fully known, but it is probable that the principal one is geometric, which is to say that, in the course of fallout, the contamination density of FP on the skin or clothing will probably be less than on the ground and will remain on the skin for shorter periods of time. The committee recommends:

XIII. Action should always be taken to prevent or reduce skin contamination, but the problem becomes particularly urgent when the accumulated dose (γ-dose to the body) exceeds, or is likely to exceed, 64 r in a 48-hour period or when the measured contamination is greater than 2 $\mu c/cm^2$ at any time on the skin.[9]

Monitoring of contaminated skin can be performed with field instruments.[10] Because of the variations that may be expected in decay rate depending on the nature and age of the radioactive material, it is difficult to set a definite level for contamination density of skin beyond which decontamination or other action is mandatory. A conservative value, however, is 2 $\mu c/cm^2$, except for very old fission products.

9. The equivalences on which this recommendation is based are: 64 r = 600 $\mu c\text{-}hr/cm^2$ on the ground. Skin contamination is taken as one-sixth surface contamination or 100 $\mu c\text{-}hr/cm^2$. This is roughly half the exposure required to cause recognizable injury to skin.

10. The measurements must be made in a "clean" area and, to be meaningful, must be done systematically according to an approved technique.

6. BIOLOGICAL AND MEDICAL CONSIDERATIONS

6.1. General

A large-scale release of fission products or other radioactive material (see Table 2.2) constitutes a hazard to everyone exposed to a radioactive cloud or in a radiation field. In addition to the immediate danger from fallout and other perils related to the accident or the enemy attack, there are long-range problems of protracted exposure to radiation and the effect of contamination on the subsequent use of the land for agriculture.

Radiation injury is used as a collective term to describe all the effects on human beings. It includes every grade of severity from the undetectable to the fatal. It also includes late somatic effects and genetic injury. The nature of the injury, the seriousness, and outcome depend, first, on such radiological factors as the type of radiation (gamma and/or beta), the dose rate, the equivalent residual dose (ERD), the density of contamination of the skin, and the body burden of radionuclides deposited internally and, second, on the biological action of ionizing radiations. The relationship between dose and effect in man is not so well documented as in laboratory animals and in some kinds of livestock. For reasons discussed later, there is necessarily some uncertainty in a forecast of the consequences of a particular dose of radiation, and this is true not only for the individual but also for a group of people. Nevertheless, decision-making in a radiation emergency requires a system for predicting the outcome of exposure—a need that this report is endeavoring to fulfil.

6.2. Biological Features of Radiation Injury

The biological action of ionizing radiations[1] is related in a complex fashion to the total dose absorbed, the dose rate, and the radiation quality. Broadly speaking, radiation acts like certain cumulative chemical poisons (for example, arsenic or alcohol) rather than like any of the usual causes of injury and death (blast, fire, missiles, flying debris, etc.) in peacetime catastrophes or in war. The clinical characteristics shared by radiation and cumulative chemical poisons include the following:

(a) Large single doses cause serious sickness or death, depending on the size of the dose and on individual susceptibility, except that very large doses are invariably lethal.

(b) Small daily doses can be tolerated over a long period of time. The total amount received in this fashion without causing any illness may be many times greater than the size of the single lethal dose.

(c) Combinations of large single doses and repeated small doses have intermediate effects.

(d) The ability of the body to recover from a large, single dose and to tolerate much larger total amounts received as repeated small doses depends on such biological processes as repair of injury, elimination, etc.

The similarity between radiation and a typical cumulative poison is demonstrated in Table 6.2. This is not intended to show that the mode of action of radiation and arsenic are the same but rather to illustrate certain features of the dose-effect relationship. These biological characteristics of injury by radiation indicate the difficulty in predicting the clinical outcome of any particular dose of radiation unless there is also a statement of the manner in which and the time during which the exposure occurred. For example: a

1. The various theories that have been proposed to account for the harmful effects of ionizing radiations are beyond the scope of this report.

TABLE 6.2. COMPARISON OF TYPICAL DOSE-EFFECT RELATIONSHIPS FOR CUMULATIVE TOXIC AGENTS

Effect	Whole-Body γ-Radiation	Arsenical Compounds
MPD: Weekly dose that does not cause recognizable sickness	0.1 - 1.0 r	Ingestion: < 9.0 mg* Inhalation: < 16.0 mg†
Largest single dose that does not cause disabling sickness in majority (9/10) of people.	200 r	50 - 75 mg‡
Median lethal dose (single)	450 r	150 - 250 mg
Accumulated dose in first year that will probably not cause disabling sickness in majority of people	1,000 r§	3,500 mg
Lifetime doses that have been tolerated	More than 2,500 r#	More than 15,000 mg
Late effects	Leukemia Cancer of skin Sterility	Cancer of skin Cirrhosis of liver Sterility

*Based on permissible amount in urine: 0.-0.85 mg/l (N. I. Sax, Dangerous Properties of Industrial Materials [New York: Rheinhold, 1957]).

†Based on permissible maximum air concentration: 0.5 mg/m^3 for a 40-hour week (ibid.).

‡Data on poisoning from E. V. Kandel and G. V. LeRoy, "Chronic Arsenical Poisoning during Treatment of Chronic Myeloid Leukemia," Archives of Internal Medicine, 60: 846, 1937.

§Provided that the exposure occurs in such a fashion that ERD does not exceed 200 r.

#It has been estimated that many early radiologists received accumulated doses of several thousand r over their professional careers.

whole-body dose of 600 r may be lethal when received as a single exposure or during a period of 4 days or less. The same accumulated exposure dose protracted over a period of 20 years and delivered in equal daily amounts (that is, less than 0.1 r/day) should not cause any recognizable clinical effect, although there may be signs that can be demonstrated by sensitive laboratory tests. When a portion of the total 600 r dose—one-half, for example—is received as a brief dose and the remainder is received as a protracted dose at the rate of 1.0 r/week, the following result can be expected: The person will become sick and vomit during, or shortly after, the onset of the brief exposure (the chances are about 9 out of 10); approximately 3 - 4 weeks later, he will develop symptoms of moderately severe radiation sickness. The chances are about equal (odds of 1 to 1) that medical care and, in some cases, hospitalization will be necessary. In an otherwise healthy adult the likelihood of death following a brief dose of 300 r is probably less than 1 in 10, and recovery from the acute radiation sickness should be complete. So far as is known at present, protracted exposure to 1 r/week for 6 years should not cause any clinical symptoms, although it may be possible to demonstrate some effects of radiation by means of laboratory methods.

Regardless of the fact that recovery from acute radiation sickness has occurred (first and third example, above) or that there has been no clinical illness (second example), it is generally believed that genetic injury is the same in each case, so that children conceived after the accumulated dose totaled 600 r, in each instance, have the same probability of receiving the same number of additional abnormal genes. In contrast to the late genetic effects of radiation, it is believed by many that late somatic effects, such as leukemia and shortening of the life-span, are more likely to be the result of large brief exposures or of protracted exposure substantially in excess of 1 r/week. Thus, in the example given above, people who survived 600 r should have a higher incidence of leukemia and a shorter life-span than those who survived 300 r, while the people exposed to 0.1 r/day for 20 years might be indistinguishable from the general, non-exposed population.

The example demonstrates two important features of radiation as a cause of injury: First, an unqualified report of total accumulated dose or of exposure dose (600 r, in this case) is of little value in a system for predicting outcome. Additional information is necessary, namely, the details of the manner in which the dose was received. Second, the outcome of exposure to radiation can be expressed in terms of probability.

6.3. Statistical Features of Radiation Injury

A given dose of radiation does not have the same effect on everyone. Biological variation—that is, differences between individuals in susceptibility to radiation, toxic chemicals, bacterial infections, etc.—is characteristic of all living things. In laboratory studies of the effect of radiation and of toxic chemicals on animals, it is customary to determine the dose that will kill half the animals exposed: this is the median lethal dose (MLD) or 50 per cent lethal dose (LD50).[2] The term implies that the fractional probability of dying is 0.5; or the odds are even (1 to 1) of surviving; or there is 1 chance in 2 of dying. In suitably designed experiments, the lethal effect of other doses can be estimated: the 25 per cent dose (amount that kills 1 out of 4), the 75 per cent dose, and so on. The same data are used to calculate the error or the uncertainty associated with the estimate of the MLD, or the 25 per cent dose, etc. Such experiments provide a system for predicting outcome (death or survival) along with a statement of the uncertainty of the prediction under the conditions of the experiment. This uncertainty is biological and is not the same as the instrument error, which is the uncertainty of

2. It is customary to qualify the LD50 with respect to the time after the dose during which deaths are attributed to it. In radiation research with small animals, the time is usually 30 days: LD50 - 30 days; with large animals (pigs, burros, etc.) the interval may be 60 days. In case of man, deaths due to radiation are infrequent later than 8-10 weeks after exposure to large, brief doses.

the measurement of the dose. Statistical studies of the lethal effect of a brief, single, whole-body exposure demonstrate a fairly consistent pattern in all species:

(1) The dose which causes few deaths (e.g., the 5 per cent lethal dose; odds of surviving are 20 to 1) is about half the MLD.

(2) The 95 per cent lethal dose (chances of surviving are 1 in 20) is less than twice the MLD.

(3) In well-planned experiments using large animals, the error, or the uncertainty, of the MLD may be as little as ± 10 per cent.

The uncertainty—or the error—of the MLD implies that the dose which kills half the animals exposed may be anywhere from 10 per cent larger to 10 per cent smaller than the value stated.

The median lethal dose is not the same for all species, but varies from about 800 r in the rabbit to less than 300 r in the dog.[3] There is little statistical information for any species on other dose effects, such as sickness, impaired capacity to work, etc. Although a human population is heterogeneous and the spread of susceptibility may be greater, it is reasonable to assume that man responds to brief doses of radiation in the same fashion as do animals, so that the 5 per cent dose (few deaths expected) should be about half the MLD, and the 95 per cent dose (few survivors expected) should be less than twice the MLD, and intermediate doses should be responsible for death rates proportional to the dose. The human MLD has not been determined experimentally, and the value most commonly used, 450 r, is recognized to be an approximation.

The statistical problem is more complicated when exposure is protracted. Table 6.3 gives the results of exposure of several species to protracted doses of γ-radiation. The difference between species is best explained by a difference in the efficiency of the mechanism for the repair of radiation injury. At the present time, no one knows with certainty whether man resembles the burro (ra-

3. Values cited are for brief, whole-body exposure to 250-kvp X-rays.

TABLE 6.3. COMPARISON OF BRIEF VS. PROTRACTED EXPOSURE AND THE MEDIAN LETHAL DOSE*

Species	MLD,† Single Dose (r)	MLD, Protracted Exposure		Ratio
		Dose Rate (r/day)	Average Accumulated Exposure Dose (r)	
Burro . .	800	50	1,500	2
Guinea pig	500	25	1,700	3
Rat	800	25	8,300	10
Pig‡. . . .	600	50	8,500	14

*Source: Data supplied in private communication by John H. Rust (values for MLD rounded off to the nearest 100 r).

†Gamma radiation from cobalt-60 for burros, rats, and pigs: 250-kvp X-rays for the guinea pig.

‡Pigs used for the experiment on protracted exposure—excepting the controls—received a brief, initial dose of 360-610 r. The source of radiation for the initial exposure was Zr^{95} + Nb^{95}; Co^{60} was used for the protracted exposure. The range of the lethal accumulated dose for the pigs was 4,634 r (including the initial dose of 484 r) to 19,250 r, when no initial dose was given.

tio of protracted to brief MLD = 2) or the pig (ratio = 14) or some other species in which the capacity to recover is intermediate.

The evaluation of genetic injury and late somatic effects is entirely statistical and consists of the measurement of changes in the incidence of biological phenomena [Sec. 6.4b(6) and 6.4b(7)] which occur whether or not there has been overexposure to radiation. Large groups of people—exposed and non-exposed—must be studied to obtain significant data on the relationship between dose and late effects. On the basis of experiments with laboratory mammals and insects, some authorities have calculated (1) the amount of radiation that will double the spontaneous mutation rate in man; (2) the reduction in life-expectancy per unit of dose; and (3) the extent to which radiation increases the risk of developing leukemia. Except in the case of radiation-induced leukemia such as occurred among the Japanese survivors of the atomic bombing, there are no

firm grounds for predictions of late effects—somatic or genetic—in relation either to total dose or to ERD.

A consideration of the statistical aspects of radiation injury helps to place in proper perspective the problems of prediction and of "calculated risk." In an emergency, about the best that can be expected are "educated estimates" of dose that may be in error by at least ± 25 per cent and a biological uncertainty of ± 10 per cent at best. The committee recommends:

XIV. Any prediction of the number of casualties should be assigned an uncertainty of at least ± 25 per cent.

6.4. Clinical Features of Radiation Injury

a. General

All that is known about the quantitative immediate effects of various radiations on normal humans comes from analysis of experience with radiation therapy (sick humans), from studies of accidental exposure, from the study of the Japanese who survived the atomic bombing, and from controlled experiments with animals. Even though much of the information is indirect, more is known about radiation than about any other agent capable of causing mass casualties. In an emergency due to radioactive fallout, the casualty rate for any group of people can be predicted with considerable confidence, on the basis either of radiological exposure data or of medical evaluation of a representative sample of the group. A system of prediction consists of a classification of the varieties of radiation injuries, the clinical manifestations and prognosis of each variety, and the dose, or range of dose, or conditions of exposure, responsible for each variety.

b. Classification of Radiation Injury

(1) Asymptomatic, or inapparent, or undetectable radiation injury occurs when the brief exposure dose, or the ERD, or the dose of internal (β-γ) radiation is less than 50 r. The effects of a

single, brief dose between about 15 and 50 r can be detected when statistical methods are applied to blood-count data from a sufficiently large group of people. Presumably, the same is true for the effects of an ERD less than about 50 r. Except for the statistical change in blood count, no one will be aware of exposure in this range.

(2) Acute radiation sickness[4] (also called the "acute radiation syndrome," "whole-body radiation injury," etc.) is caused by external or internal γ- or X-radiation. Clinical manifestations include general "toxic" symptoms,[5] such as weakness, nausea, easy fatigue, etc., and specific symptoms and signs caused by damage to the gastrointestinal tract, the blood-forming organs, the central nervous system, etc. The signs[5] of radiation sickness include alterations of the blood count, excretion of abnormal substances in the urine, loss of hair (epilation), a tendency to bleed easily, etc. Radiation sickness may consist of nothing more than a decrease in the white cell count and slight fatigue, or it may be so severe that death occurs within hours of the onset of exposure. Five clinical groups can be distinguished on the basis of severity which can be correlated with the size of the dose.

Group I: Less than half this group vomit within 24 hours after the onset of exposure. There are either no subsequent symptoms or, at most, weakness and easy fatigue. There is a decrease in the white blood cell count (which is most marked in the case of the lymphocytes) and in the platelet count. Less than 5 per cent (1 out of 20) require medical care. All others can perform their customary tasks. Any deaths that occur are caused by complications. Sickness of this type has been seen after brief, whole-body doses of γ- and X-radiation in the range of 50 - 200 r. An ERD of external γ-radiation of 50 - 200 r may have a similar effect.

Group II: More than half this group vomit soon after the onset of exposure and are sick for a few days. This is followed by a period of 1-3 weeks when there are few or no symptoms. During the latent period, typical changes occur in the blood count and can be used for diagnosis. At the end of the latent period, epilation (loss of hair) is seen in more than half, and this is followed by a moderately severe illness due primarily to the damage to the blood-forming organs. Most of the people in this group require medical care. More than half will survive, with the chances of survival being better for those who received the smaller doses. Sickness of this type has been seen after brief, whole-body doses of γ- or X-radiation on the order of 200 - 450 r. An ERD of external γ-radiation of the same size will probably cause a similar illness.

Group III: This is a more serious version of the sickness described as Group II. The initial period of illness is longer, the latent period is shorter, and the main episode of illness is characterized by extensive hemorrhages and complicating infections. People in this group need medical care and hospitalization. Less than half will survive, with the chances of survival being poorest for those who received the largest doses. Sickness of this type has been seen after brief whole-body γ-radiation with doses in excess of 450 r. It is possible that an ERD of external γ-radiation of the same size will have a similar effect.

Group IV: This is an accelerated version of the sickness described as Group III. All in this group begin to vomit soon after the onset of exposure, and this continues for several days or until death. Damage to the gastrointestinal tract predominates, manifested by intractable diarrhea, which soon becomes bloody. Changes in the blood count occur early, and within a

4. Radiation sickness is described as acute when clinical manifestations occur early and do not last longer than 6 months.

5. Symptoms are what the patient complains about, e.g., headache, weakness, etc. Signs of radiation injury are observed by an examiner, e.g., hemorrhage, loss of hair, etc., or detected by a laboratory test, e.g., low white cell count, etc.

few days the total white cell count may be less than 500 per mm^3. Death occurs before the end of the second week, and usually before the appearance of hemorrhages or epilation. All in this group need care, and it is unlikely that many will survive. Sickness of this type has been seen after brief, whole-body exposure to γ-radiation in excess of 600 r. During protracted exposure to external γ-radiation, it is not probable that an illness of this type would be the first evidence of injury.

Group V: This is an extremely severe illness in which damage to the brain and nervous system predominates. Symptoms, signs, and rapid prostration come on almost as soon as the dose has been received. Death occurs within a few hours or a few days. Sickness of this type has been seen after a brief whole-body exposure to γ-rays in excess of several thousand r and to equivalent doses from neutrons.

(3) Chronic radiation sickness.[6] There is almost no information about the effects of protracted external exposure of man. Some radium chemists and radiologists who worked with radiation before the hazards were recognized frequently developed a progressive refractory anemia and died either from the anemia or from complicating infections. Animal experiments provide little additional information concerning the patterns of chronic radiation sickness that may occur in man. At present, we cannot tell the size of the ERD that will be lethal, when exposure is protracted over a period of years.

(4) Radiation injury to the skin

(a) Epilation, or loss of hair, is caused by exposure to γ-radiation, β-radiation, a mixture of γ and β, or to X-rays. Regardless of the dose, epilation is unusual before the second week after the onset of exposure. Among people exposed only to mixed

6. The sickness is described as chronic when the symptoms and signs persist beyond 6 months.

radiation from fallout or to the initial nuclear radiation (gamma rays plus neutrons), epilation is a reliable indicator of the existence of radiation injury. It seldom occurs when the dose is less than 200 r. Beta-ray injury due to contamination of the scalp by radioactive fallout particles is additive to gamma-ray (and neutron) injury, so that epilation is more frequent and more extreme in individuals exposed to both forms of radiation. A single "hot" particle of FP stuck in the hair can cause a bald spot approximately one-half inch in diameter. The hair grows back if the dose has not exceeded 600 r.

(b) Radiation dermatitis is caused by exposure to β-radiation or γ-radiation. Beta-ray burns result from radioactive fallout retained on the skin, from exposure to the "beta-ray bath" of a fallout field, and from exposure to a beam of electrons. The skin of the hands may be damaged by even brief handling of objects heavily contaminated by fresh FP. The reactions of the skin depend on the size of the dose absorbed and the energy of the radiations and are similar for all types of exposure. Four clinical types of skin injury can be recognized, in the following order of severity:

Type I: Erythema is equivalent to a thermal burn of the first degree or a mild sunburn. At the time of exposure, there may be a sensation of warmth or itching; the redness appears 2 - 3 weeks later, the interval depending on the dose. Medical care is not necessary, and ability to work is not impaired.

Type II: Transepidermal injury (dry or wet dermatitis) is equivalent to a thermal burn of the second degree. Blisters form and break open, leaving raw, painful wounds which are vulnerable to infection. At the time of exposure, symptoms similar to those in Type I are noted. The latent period is shorter, however, and blisters appear within 1 - 2 weeks, depending on the dose. Recognizable injury of this grade requires a skin dose in excess of 1000 r, which means an exposure in excess of 200 μc-hr/cm^2. The need for medical care depends on the size and severity of the beta-ray burn. The same is true for interference with the ability to work.

Type III: This is a more serious version of Type II, caused by much larger doses of radiation. Injury of this sort has been observed after handling fresh FP and material—e.g., targets—in which radioactivity was induced during laboratory experiments by neutron bombardment and also after accidental exposure of hands to the direct beam of an electron accelerator. The appearance resembles a scalding or a chemical burn. Pain occurs promptly and is intense. Medical care is urgently needed. The skin dose responsible for burns of this severity is probably on the order of 5,000 r.

Type IV: Chronic exposure of the skin to X-rays, γ-rays, or β-rays over a period of months to years causes an eczema-like condition. Once it has developed, it seldom heals completely. Skin cancer occurs in a large (but unknown) proportion of people with chronic radiation dermatitis. Dosage factors are not known.

(5) Internal radiation injury. There is limited human experience, to date, with internal deposits of radioisotopes large enough to cause acute radiation sickness. Nevertheless, this is the effect that is anticipated on the basis of animal experiments. Isotopes of iodine are selectively deposited in the thyroid gland, and the dosimetry of this reaction is well known because of the clinical use of iodine-131. Radioisotopes of strontium and of several other elements are selectively deposited in the bones, and the dosimetry of these reactions can be inferred from clinical experience with radium and mesothorium. Insoluble FP in the gastrointestinal tract may cause nausea, vomiting, diarrhea, and serious damage to the lining of the stomach and bowel.

It is probable that a large exposure to a radioactive cloud will cause acute radiation sickness due to total-body exposure. If this is not fatal, the radioactive isotopes deposited in bone may damage bone marrow at some later time.

(6) Genetic effects of radiation. Exposure of sex cells to radiation causes gene mutations[7] to occur in excess of the spontaneous mutation rate. This genetic injury does not affect the exposed individuals in any way and can be detected only by statistical studies of their descendants. The expression of genetic injury in children one, or both, of whose parents were exposed to radiation consists of (1) a change in the sex ratio (i.e., number of male versus female babies born); (2) an increased incidence of abortions and stillbirths; (3) an increased incidence of malformed babies; and (4) an increased rate of infant mortality during the first year of life. Among later descendants (the second, third, etc., generations) of people who received genetic injury, it is expected that there will be an increased incidence and prevalence of hereditary disorders. Most authorities believe that the extent of genetic injury is approximately proportional to the total dose of radiation accumulated up to the time of procreation, although there may be some recovery, as in the case of ordinary radiation injury.

It is not possible at present (1961) to predict the amount of genetic injury caused by a given dose of radiation with the same degree of confidence as that which applies to the prediction of acute radiation sickness or injury to the skin. The unit employed to describe the dose-effect relationship for radiation-induced mutations is the representative doubling dose—the amount of radiation that doubles the spontaneous mutation rate. For man, the representative doubling dose is assumed to lie between 10 and 100 r. Unfortunately, there is no satisfactory way to use this estimate for planning or operations because of a lack of specific information on (1) the spontaneous mutation rate, (2) the prevalence of inherited disorders, and (3) the extent to which genetic factors are responsible for abortions, stillbirths, and infant mortality. Using pessimistic

7. A mutation is a change in the properties of a gene, which is the fundamental unit of heredity. Individual genes "control" specific biochemical reactions, and any deleterious change is a disadvantage that may be expressed as abnormal development or abnormal function. Factors other than radiation are known to cause gene mutation.

assumptions, one calculation indicates the following genetic effects on descendants of survivors of a nuclear war who received an average total dose of 250 r: major defects in newborn babies of successive generations ultimately might increase by as much as 25 per cent—this means that 5 per cent of all newborns would be defective, in contrast to the present rate of 4 per cent in the United States. A comparable increase in infant mortality during the first year of life would also occur, so that the 1961 rate of 26 deaths per 1,000 live births would become about 33 per 1,000—the infant mortality rate recorded in 1946.[8] However, other circumstances of a nuclear war and of the postattack reconstruction period would certainly increase infant mortality to a much greater extent than that predicted for genetic injury.

In the absence of a satisfactory quantitative approach to the problem of prediction of genetic injury, the committee recommends:

XV. The possibility of genetic injury should not be a principal determining factor when making decisions during a war emergency.

Finally, it is important to emphasize that genetic injury will be smaller if controllable exposure is minimized for all people who are still capable of procreation.

(7) Late somatic effects of radiation. Late effects occur many months or years after the onset of overexposure and include leukemia, life-shortening, cataracts, sterility, cancer of any site, and, in the case of fetal irradiation, a variety of developmental defects. A late effect can—but may not necessarily—develop in a person who has recovered from acute radiation sickness or in a person who has never been sick in spite of protracted overexposure. None of these conditions is caused uniquely by radiation—they can afflict

8. Data from the National Office of Vital Statistics.

people who have never been exposed to more than the natural background plus the X-rays used in ordinary medical and dental examinations. What the additional radiation does, apparently, is to increase the probability of these troubles (e.g., leukemia, etc.) above the standard rate for persons of their age.

Prediction of the effect of any particular total dose or ERD on any or all of the late effects mentioned above depends, first, on age-specific risk rates (which are available) and, second, on information that is not available (1961) on the extent to which radiation alters the various rates. A consensus of experts on the several late effects follows.

(a) Sterility or reduced fertility occurs in many cases of non-fatal acute radiation sickness but is temporary in most people. It takes a dose of at least several hundred r to the ovaries to cause sterility. Even larger doses are needed for the male. Complete recovery of fertility may take as long as several years after cessation of exposure.

(b) Leukemia. The risk of developing leukemia is definitely increased by overexposure to radiation. Leukemia has appeared in the Japanese who survived the atomic bombing, with the majority of cases occurring during the first 10 years (1945-55). It seems that the incidence of radiation-induced leukemia is approximately proportional to the brief dose received. Protracted exposure to X-rays for therapeutic purposes has also increased the incidence of leukemia. Among the Japanese who survived the largest doses (that is, who were closest to the point of detonation) the incidence of leukemia was about 50 times the standard 10-year rate. A 50-fold increase means that during a 10-year period 1.5 per cent of survivors (age 25-34 years) may develop leukemia instead of 0.03 per cent—the standard 10-year risk rate for this age group in the United States.

(c) Cataract. The incidence of cataract increases with the dose. Among the Japanese who survived the atomic bombing, there were about as many cases of cataract as of leukemia: namely 100-150. All but two of these consisted of minor opacity of the lens that did not interfere with vision.

(d) Cancer of Any Site

(i) Cancer of the skin occurred frequently among the pioneer radiologists. Individual exposures were probably small but were repeated over a long time. The latent period between the onset of exposure and the appearance of skin cancer can be as long as 20 years. It is seldom possible to determine the size of the total dose responsible. Brief local exposures in excess of 1,000 r have also caused skin cancer.

(ii) Cancer of the lung is an occupational disease of uranium miners. It is caused by inhalation of the radioactive gas, radon, and by radioactive dusts and aerosols containing several radionuclides.

(iii) Cancer (sarcoma) of bone has developed in people who accidentally swallowed radium while engaged in painting luminous dials, etc. It has also occurred—before the late effects were appreciated—when radium salts were given by mouth or intravenously as medicine. The latent period for radium sarcoma ranges from 5 to 35 years.

(iv) Other cancers. Comparatively few other cancers in man have been reported as caused by external or internal irradiation, but abundant evidence for this late effect is available from experiments with other mammals.

(e) Shortening of Life-Span. In experiments on animals, total- or partial-body irradiation—brief, divided, or protracted—is found to shorten the average length of life. Extrapolation to man has led to estimates that each roentgen of total body exposure shortens life from 1 to 10 days, but no observations are available to confirm this. Average life-expectancy at birth in the United States in 1959 was 69.7 years (at age

45, it was 29.3 years). Depending on which estimate is used (1 day or 10 days per r), the survivors of a nuclear war whose average total dose was, for example, 500 r might have their life-span shortened by as little as 1.5 years or by as much as 14 years.

(f) Fetal Irradiation. The experience in Japan indicated that most pregnant women had a miscarriage shortly after the bombing if radiation exposure was large enough to cause signs and symptoms of acute radiation sickness. A few fetuses survived to term and were delivered successfully. It is reported that some of these displayed developmental defects comparable with those observed in experimental animals irradiated during pregnancy. There are, however, no reliable data on which to base predictions of the outcome of a pregnancy complicated by exposure to radiation.

Because of the many uncertainties involved in evaluating them, the committee recommends:

XVI. The possibility of late somatic effects of radiation should not be a principal determining factor when making decisions during an emergency.

c. Uses of a Scheme of Injury Classification

The classification of radiation injuries given in the previous section (6.4b) is comprehensive and consists of 11 entities, most of which have been studied in man. The classification scheme is summarized in Table 6.4. It can be used equally well for two purposes:

(1) To estimate exposure dose. If some or all of the members of a group exposed under similar conditions develop a combination of symptoms and signs such that a particular clinical diagnosis, e.g., acute radiation sickness, Group II, can be made, it is proper to assign the appropriate value for the exposure dose. Estimates of brief total-body dose,

TABLE 6.4. SUMMARY OF RELATIONSHIP BETWEEN DOSE AND INJURY

Type of Exposure	Type of Injury	Probable Condition of Majority during Emergency: Medical Care Required	Probable Condition of Majority during Emergency: Able To Work	Probable Mortality Rate during Emergency*	Comment
A. Brief, whole-body, γ-rays; 12 - 50 r	Asymptomatic	No	Yes	0	Similar effect from ERD of 12-50 r
50 - 200 r	Acute radiation sickness, Group I	No	Yes	Less than 5 per cent	Similar effect from ERD of 50-200 r
200 - 450 r	Acute radiation sickness, Group II	Yes	No	Less than 50 per cent	Probably similar effect from ERD of 200-450 r
450 - 600 r	Acute radiation sickness, Group III	Yes	No	More than 50 per cent	Uncertain effect of ERD in excess of 450 r
More than 600 r	Acute radiation sickness, Groups IV and V	Yes	No	100 per cent	Uncertain effect of ERD in excess of 450 r
B. Internal deposit	Acute radiation sickness, with severity proportional to internal dose	Varies	Varies	Varies	No reliable data on relation between internal dose and whole-body brief external dose
C. Beta-irradiation of skin less than 1,000 r†	Radiation dermatitis, Type I	No	Yes	0	Associated with whole-body radiation dose of variable size
1,000 - 5,000 r	Radiation dermatitis, Types II and III	Yes	No	Less than 50 per cent	Mortality related to area of burn
More than 5,000 r	Radiation dermatitis, Type IV	Yes	No	More than 50 per cent	Mortality related to area of burn

*This refers to acute mortality: death during first 6 months after onset of exposure.

†Beta-ray dose is usually stated in rads.

ERD, skin dose, or internal dose made in this way should ordinarily not be in error by more than ± 25 per cent. This use of the classification is important because it permits validation of data furnished by the radiological staff.

(2) To predict the outcome of exposure already received, as well as the outcome of accumulated dose, plus any additional dose that is required or contemplated by the officials in charge of the situation. Prediction of outcome is probably somewhat less certain than an estimate of dose based on a competent clinical study of a group of casualties. Nevertheless, in an emergency, decisions must be made and directives issued long before the appearance of definite clinical manifestations of radiation injury.

There are significant relationships between the different kinds of radiation injury, which may be more readily appreciated from the tabular summary (Table 6.4) than from reading the text.

6.5. The Problem of Protracted Exposure

In the case of peacetime radiation emergencies, there is little reason to anticipate the need to regulate protracted exposure for weeks or months if relocation of the exposed population is possible. In the case of a large-scale attack with nuclear weapons, relocation may be impossible either for the entire population or for certain segments of it (e.g., defense-plant workers, security forces, etc.). Under these circumstances, decisions will be required with respect to the daily dose that may be authorized for periods of time as long as 1 year after the beginning of exposure. In such a case, the adoption of the ERD provides a reasonable basis for decision-making. The responsible authority will have to deal with two related problems: first, when to allow able-bodied survivors to leave shelter to participate in clean-up, maintenance of the economy, and reconstruction and, second, how to control the exposure of these survivors so that they will not develop acute radiation sickness severe enough to require medical care, hospitalization, and removal from the labor force.

Using the ERD as a guide, it should be possible to regulate the daily dose in such a fashion that an established limit (on ERD, that is) can be adhered to. The daily dose can be controlled—in theory at least—by regulating the length of time authorized out of shelter or at a particular job in the radiation field. In order to do this, reliable personal dosimeters and competent radiological personnel are necessary. Examination of Figure IIc of Appendix II demonstrates that, during the first 3 months, recovery from a brief dose of 200 r more than offsets the buildup of ERD when the protracted exposure is less than 3 r/day. At the end of the third month, all possible recovery from the brief dose will have occurred, and the ERD will be about 160 r. Continued exposure at 3 r/day for a few more months will lead to an ERD in excess of 200 r.

The committee has little confidence in the usefulness of ERD when the brief dose is in excess of about 300 r or when the ERD itself is much in excess of about 250 r. It should be understood that the concept of ERD is compatible with what is known about the effects of radiation on man, but no experiments have been performed to test its validity. Until experience has been gained with the application of ERD in an emergency, its use should not be extended beyond about 1 year. In spite of all these uncertainties, there does not appear to be any better way to deal with the protracted exposure that will inevitably occur following an attack with nuclear weapons. Therefore, the committee recommends:

XVII. The equivalent residual dose (ERD) should be used to plan protracted exposure.

It is entirely feasible for the decision-maker—if he wishes to do so—to establish a maximum ERD for people who are not likely to become parents because of age or other circumstances and to establish a lower limit of ERD for those still capable of procreation.

6.6. System for Predicting Outcome of Human Exposure

The classification of radiation injuries in Table 6.4 is an elaborate system for predicting outcome that is suitable for planning and training exercises but is too cumbersome for operational use in an emergency. The five categories of radiation sickness, the five categories of skin injury, and various possible patterns of brief exposure, protracted exposure, and internal deposit, added to all the other circumstances of disaster or a war, provide so many combinations of information and so many options for action that no one person could make consistent decisions. A simpler system can be devised based on clinical factors, as shown in Table 6.6a. Even more simple is the system recommended by the committee, Table 6.6b, in which there are only three possible consequences of exposure.

There is agreement among most authorities that a single whole-body dose of 200 r will not affect the average adult to the extent that he is incapable of performing his ordinary activities. In fact, whole-body doses of 200 - 300 r have been given to many patients with advanced cancer without any manifest harmful effect on their physical condition. Changes in the blood count occurred, as was expected, but these were not sufficient to require medical treatments. The Marshall Islanders who had the largest exposure to fallout received about 175 r over a period of 36 hours. In this group, which included people of all ages, the only evidence of acute radiation sickness (Sec. 6.4b, Group II) was vomiting on the day fallout occurred (about 10 per cent reported this symptom) and changes in the white blood cell count and platelet count several weeks later. There is also general agreement that an ERD of 200 r, or less, should not cause radiation sickness severe enough to require medical care in the majority (9 out of 10) of healthy adults. These are the reasons that the committee has chosen, arbitrarily, 200 r as the dividing line between doses that will and will not cause sickness that requires medical care.

TABLE 6.6a. SYSTEM FOR PREDICTING OUTCOME OF EXPOSURE BASED ON CLINICAL FACTORS

ERD, or Brief γ-Ray Dose (r)	Grade of Severity	Clinical Characteristics	Approximate Dose to Skin (rads)
Less than 50 . .	A	No symptoms, no signs	
50 - 200	B	Signs present, no symptoms except nausea and vomiting	Up to 1,000
200 - 450	C	Signs and symptoms present; up to 50 per cent fatal	1,000 - 5,000
More than 450 .	D	Signs and symptoms present; over 50 per cent fatal	More than 5,000

TABLE 6.6b. RECOMMENDED SYSTEM FOR PREDICTING OUTCOME OF EXPOSURE

Range of Brief, Whole-Body, γ-Ray Dose, or of ERD (r)	Consequence of Exposure	Approximate Dose to Skin (rads)
Less than 200	Medical care not required	Less than 1,000
200 - 600	Medical care required during emergency or subsequently (but excluding late effects)	More than 1,000
More than 600	Death	More than 5,000

Regardless of the system used, the effects of a brief exposure dose that are known with greatest confidence are as follows:

	Approximate Dose
(1) Smallest effect detectable by statistical study of blood counts of a large group of people	15 r
(2) Smallest effect detectable in an individual by laboratory methods	50 r
(3) Smallest dose that causes vomiting on day of exposure in at least 10 per cent of people	75 r
(4) Smallest dose that causes epilation in at least 10 per cent	100 r
(5) Largest dose that does not cause illness severe enough to require medical care in majority of people (more than 9 out of 10).	200 r

The values known with less, little, or no confidence include the following:

(1) Median lethal dose

(2) Dose that kills 10 per cent; dose that kills 90 per cent

(3) Ratio of MLD for protracted exposure to MLD for brief exposure

(4) Area of skin necrosis (death of skin) that causes death in 50 per cent of the cases

(5) Body burden of radioactive material equivalent in effect to an ERD of 50 r, 200 r, etc.

(6) Effect of ERD in excess of 200 - 300 r

6.7. Prediction of Number of Persons Requiring Hospitalization, Etc.

Military medical authorities have studied the logistics of handling wartime casualties not only from "conventional," low-yield, fission bombs but also from high-yield, thermonuclear weapons. Using the same sources of information that are available to the NCRP, detailed schedules have been prepared to predict the following:

(1) Casualty rate versus dose
(2) Hospitalization rate versus dose
(3) Time after bombing at which hospitalization will be required versus dose
(4) Duration of hospital stay versus dose
(5) Requirement for medical supplies versus dose
(6) Death rate for hospitalized casualties versus dose

Some of these estimates have been published and used to develop computer solutions for military and civil defense training exercises. As useful as these procedures are for planning and training purposes, more simplified approaches are being recommended here for use during an emergency. Decision-making in an emergency will be difficult enough when the simplest system is used to predict outcome of exposure.

6.8. Work Capacity

Laymen and physicians are thoroughly familiar with the fact that a sick man or an injured man cannot do as much work as a healthy one. It is also well known that chronic disease, starvation, and thirst interfere with work capacity. There are countless records of refugee trains, transportation of prisoners, death marches, and the like in which the sick and wounded died when subjected to exertion and deprivation that were tolerated by healthy people. In spite of familiarity with the problem, no one knows how to quantitate this common observation. It would be convenient to be able to predict the reduction in physical effectiveness due to a variety of common toxic agents, and, if it were possible, the surgeons of the armed forces would have done so long ago. It is simply not reasonable to expect physicians to estimate the per cent reduction in work capacity resulting from exposure to any amount of radiation less

than the dose that causes a clinically evident form of radiation sickness or skin injury severe enough to require medical care. The committee concludes that it is not possible to make close predictions of the potential reduction in work capacity prior to the onset of obvious illness following exposure to radiation. In the simplest terms, a person's work capacity declines when he becomes sick or when complications develop in connection with superficial wounds. Until evident illness occurs, the commander has no alternative but to consider the individual as fit for duty. Any other attitude can only lead to administrative chaos resulting from conflicting opinions offered by physicians, radiological monitors, supervisors of the labor force, and others.

6.9. Infection

The committee examined proposals to consider the risk of infection as one of the factors influencing decision-making in an emergency. Such clinical evidence as was available indicated that persons sick as a result of radiation injury were unusually susceptible to infection. No clinical data could be found to support the notion that asymptomatic radiation injury affected resistance to infection or immunity. Studies of experimental animals were reviewed, but the committee believes that none were sufficiently cogent to justify extrapolation to human beings.

7. EFFECTS ON LIVESTOCK AND AGRICULTURE

7.1. General

In an emergency, the principal consideration with respect to food-producing animals is not their survival, as such, but their availability as a food resource. They should be dealt with, first, from the standpoint of the immediate requirements of food for the human population of the affected region and, second, as a continuing resource during recovery from the disaster. Exposure to gamma radiation does not impair the nutritional value of meat, even though the ensuing radiation sickness and concomitant bacterial infection may affect it adversely. Carcass meat and food products contaminated by fallout may be found to be suitable for human consumption, depending on the amount and kind of radioactive material present and the urgency of the needs of the people.

7.2. Livestock

Livestock may be injured or killed by a radioactive cloud or by fallout. The MLD for farm animals has been determined experimentally and is much more certain than the MLD for man. For brief exposures (i.e., over a period shorter than 4 days), the 50 per cent lethal dose is about 650 r ± 10 per cent and is approximately the same for mature cattle, sheep, pigs, and burros. When the dose is protracted, pigs are found to be unusually resistant, as described in Section 6.3, above. When the lethal dose is a single or brief exposure, most farm animals die during the second or third week. Animals that survive are also exposed to internal radiation from eating fallout that contaminates the pasture land. During a nuclear war, it may be desirable under some circumstances to round up exposed animals and slaughter them promptly for food.

Exposure to external γ-radiation does not affect the food value of the meat. However, meat may become contaminated by ingested fallout. Such contamination will decrease because of radioactive decay while the meat is in storage. Also, such contamination may be avoided by proper selection of portions to be consumed.

7.3. Chickens

Chickens that survive a dose of several hundred r are able to resume egg-laying. Those from Rongelap in the Marshall Islands, for example, started laying again about 40 days after exposure. The eggs were radioactive, but the majority of radioactivity—70 - 80 per cent—was in the shells. Strontium-89 was the most important fission product in the edible portion, and the amount was insignificant—less than 0.5 per cent of the MPC for water. It is probable that chickens will not lay if the radioactive body burden is large enough that their eggs are unfit to eat. The MLD for chickens is two to three times greater than for farm mammals. Ordinarily, chickens are fed stored foods, and, because of this, it is probable that chickens can serve as a major relatively uncontaminated source of food early in the postdisaster period.

7.4. Milk

Milk may be contaminated with radioisotopes from fallout; the most important of these are iodine and strontium. Cows that have received a large dose of external γ-radiation or a large dose of internal radiation from ingested fallout will soon cease to give milk. The fact that a cow still produces is evidence that radiation injury is minimal and that the body burden is not great. Nevertheless, action may be required regarding the disposition of the milk. A realistic decision requires accurate radiological measurement of the contamination, most of which will consist of radioisotopes of iodine and strontium. Until data are available, such milk can be diverted to cheese or powdered-milk plants for processing. The products can be stored while radioactive decay continues and until Public

Health officials make decisions concerning the wholesomeness of these foods.

7.5. Sea Food

Sea food contaminated by fallout should be handled in the same manner as milk. It can be frozen and stored until precise radiological measurements are obtained. The final decision in such cases should be left to proper officials, who may be guided by statements published by the NCRP on permissible amounts of radionuclides in the human body and in material entering the body.

7.6. Standing Crops

Standing crops can be contaminated directly by fallout and also can absorb radioactive isotopes from contaminated soil. Except when the emergency and the time of harvest coincide, decisions regarding the handling of standing crops are not urgent. Radiological data should be secured before any action is taken to destroy food crops.

APPENDIX I

1. ICRU Definitions of Radiation Quantities and Units[1]

1.1. Absorbed dose of any ionizing radiation is the energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest.

Note.—(a) In the definition of absorbed dose the concept of "energy imparted to matter" refers to all of the energy which appears as ionization, excitation or changes of chemical bond energies during the period of observation and within the specified mass of material. Energy as here defined includes, for example, the energy of lattice displacements but not the energy associated with changes of rest mass (e.g., after neutron capture). If nuclear excitation occurs, the fraction of the energy released and which remains in one of the above forms within the specified mass is counted at the time of decay.

(b) The quantity "absorbed dose" can apply to any material. Moreover, in a constant radiation field its magnitude will be different in different materials and hence the material should always be specified.

[Note (c) of the original is here deleted.]

1.2. The unit of absorbed dose is the rad. 1 rad is 100 ergs/g.

[Paragraphs 1.3 and 1.4 of the original are here deleted.]

1.5. Absorbed dose rate is the absorbed dose per unit time.

Note.—It should be pointed out that there are special situations

1. Excerpts from the Report of the International Commission on Radiological Units and Measurements (ICRU) (1959), NBS Handbook 78. (Numbers refer to paragraphs in original report.)

when the absorbed dose rate should be expressed more explicitly. For example: when the absorbed dose rate is not constant during the time of irradiation, it may be desirable to specify also the instantaneous absorbed dose rate. It is recognized that the term "instantaneous" may not always be sufficiently explicit and that perhaps a statement should be added referring specifically to an absorbed dose rate of pulsed radiation averaged over a single pulse.

1.6. The unit of absorbed dose rate is the rad per unit time.

1.7. Exposure dose of X- or gamma radiation at a certain place is a measure of the radiation that is based upon its ability to produce ionization.

[Note (a) of the original is here deleted.]

Note.—(b) Although the definition of exposure dose was purposely stated in loose terms, a more physically specific definition might be as follows: "the exposure dose is measured by the ion charge, ΔQ, of either sign, produced in air by the secondary electrons, which are produced by X- or gamma radiation in a small mass, Δm, of air divided by Δm." Note that according to the above definition, ΔQ is not the charge measured in Δm. However, under electronic equilibrium conditions, the charge produced in Δm is approximately numerically equal to ΔQ.

(c) The wording of this definition leaves open the possibility of later defining exposure dose for radiations other than X- or gamma rays.

1.8. The unit of exposure dose of X- or gamma radiation is the roentgen (r). One roentgen is an exposure dose of X- or gamma radiation such that the associated corpuscular emission per 0.001293 g of air produces, in air, ions carrying 1 electrostatic unit of quantity of electricity of either sign.

Note.—(a) According to the definition, a dose of one roentgen is obtained at a point if the electrons generated in 0.001293 g of dry air at that point produce along their track 1 esu of ions of either sign. Accurate measurements in roentgens are not obtained by actually measuring these ions. Instead the concept of electronic

equilibrium is used so that one can measure the ionization per 0.001293 g of air. According to this concept the ionization produced outside of a small mass, m, by high-speed electrons generated inside of m is compensated by ionization produced inside m by electrons generated outside of m.

(b) The corpuscular emission shall not include contributions due to secondary X- or gamma radiation produced in the quantity of air in which the corpuscular (electron) emission referred to is generated. This follows from a consideration of the actual definition of the roentgen and the concept of electronic equilibrium.

(c) It becomes increasingly difficult (because of electronic equilibrium limitations) to determine the exposure dose in roentgens as the quantum energy of the X- or gamma radiation approaches very high values. For practical purposes, 3 Mev is sometimes arbitrarily regarded as the useful upper limit of the energy range over which the roentgen should be used.

1.9. Exposure dose rate is the exposure dose per unit time.

Note.—(a) Exposure dose rate can be used to specify a field of irradiation or the output from an X- or gamma-radiation source up to 3 Mev.

(b) For quantum energies above 3 Mev, the ICRU at present is not in a position to make a firm recommendation on the specification of output from a radiation source. One may use either intensity or the absorbed dose rate at the peak of the buildup curve in a phantom under specified conditions; the latter may be derived from ionization measurements.

(c) It should be pointed out that there are special situations when the exposure dose rate should be expressed more explicitly. For example, when the exposure dose rate is not constant during the time of irradiation, it may be desirable to specify also the instantaneous exposure dose rate. It is recognized that the term "instantaneous" may not always be sufficiently explicit and that perhaps a statement should be added referring specifically to an exposure dose rate of pulsed radiation averaged over a single pulse.

1.10. The unit of exposure dose rate is the roentgen per unit time.

[Paragraphs 1.11 and 1.12 of the original are here deleted.]

1.13. The unit of quantity of radioactive material, evaluated according to its radioactivity, is the curie (c). One curie is a quantity of a radioactive nuclide in which the number of disintegrations per second is 3.700×10^{10}.

[Paragraphs 1.14 - 1.19 of the original are here deleted.]

2. RBE (Relative Biological Effectiveness), a Recognized Symbol

Relative biological effectiveness was first used to compare the biological effect. The results of such experiments usually are given now in terms of the ratio of absorbed doses. The value so obtained depends not only on the type and degree of biological damage but also upon many subsidiary variables such as the absorbed dose rate, the dose fractionation, the oxygen pressure, the pH and the temperature. It may be computed from experimental data obtained with the same or different kinds of radiation.

The U. S. National Committee on Radiation Protection and Measurements recommended (NCRP Handbook 59, 1954) the use of the RBE for the field of radiation protection in order to provide a mechanism for the addition of absorbed doses of different kinds of radiation. For this application it has become necessary to assign to different types of radiation certain agreed factors (RBE), so that the "effective" dose may be computed. These factors take into account the "critical organs," some RBE values for certain effects on these critical organs and any other relevant considerations. It would be advisable to distinguish between such agreed RBE factors and the experimental values of RBE determined as described above but agreement has not yet been obtained for this. The procedure to be followed when expressing the exposure of persons to radiation is as follows:

The absorbed dose, D (in rads), of any radiation must be multiplied by an agreed factor, RBE, whose values for different radiations are laid down by the ICRP. This product, called the RBE dose, is expressed in rems where

RBE dose (in rems) = (RBE) (D).

In the case of mixed radiations the total RBE dose is assumed to be equal to the sum of the products of the absorbed dose of each radiation and its RBE.

RBE dose (in rems) = Σ [absorbed dose in rads (RBE)].

APPENDIX II

Equivalent Residual Dose

The ERD at any time, t days, after onset of exposure can be calculated on the basis of the following assumptions:

1. Ten per cent of the injury attributed to the dose is considered to be irreparable.

2. The body repairs the remaining 90 per cent at the rate of 2.5 per cent per day.

3. Recovery after a brief exposure (i.e., delivered over a period of a few seconds to 4 days) begins 4 days after the start of the exposure.

4. Recovery is continuous during protracted exposure.[1]

The ERD at t days may be expressed as:

$$\mathrm{ERD} = D_0\,[0.1 + 0.9\,(1.000\text{-}0.025)^{t-4}] + \dot{D}\int_4^t [0.1 + 0.9\,(1.000\text{-}0.025)^{t}]\,dt\,, \qquad (1)$$

where D_0 = brief dose in r received during first 4 days,

$\dot{D}$ = protracted daily dose at a constant rate, r/day, received after the 4th day, and

t = time in days after onset of initial exposure.

Equation (1) may be expressed as

$$\mathrm{ERD} = a(t)D_0 + b(t)\,\dot{D}\,, \qquad (2)$$

where a = Multiplier for brief dose appropriate to time t, and

1. This method of calculation was chosen, arbitrarily, for convenience and because it probably fits the facts in sufficient approximation for present purposes. It was not derived directly from experimental data.

b = Multiplier for protracted dose rate appropriate to time t.

The values for a and b can be obtained from Figures IIa and IIb for any time up to one year, 365 days.

Example: 100 r is received as a brief dose within the first 4 days. An exposure of 1 r/day is received from the 4th day through the 120th day. What is the ERD at the end of 120 days?

D_0 = 100 r; a = 0.14 (see Fig. IIa),

D = 1 r/day; b = 42 (see Fig. IIb),

ERD = (0.14 x 100) + (42 x 1) = approximately 56 r.

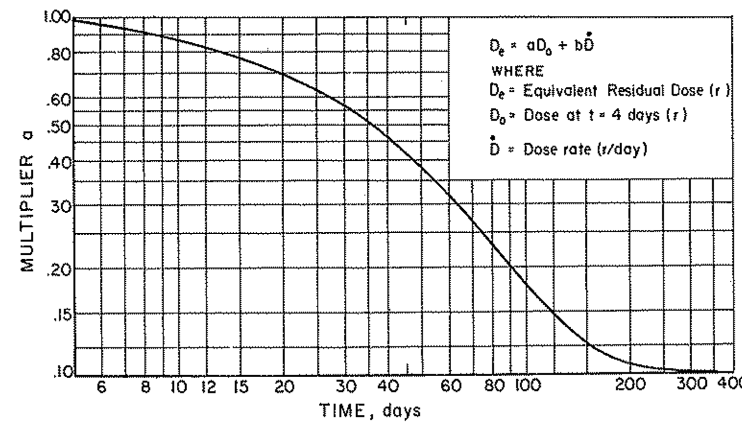

FIG. IIa.—Multiplier for initial brief dose, to be used in calculation of ERD at any time.

The extent to which recovery reduces the accumulated exposure dose and hence the likelihood of disabling illness is demonstrated graphically in Figure IIc. So long as the brief exposure dose is less than 200 r, it is probable that a protracted exposure of up to about 1.5 r/day will not result in disability, even though such exposure continues for at least 1 year. This prediction is based on the fact that the ERD will not exceed 200 r during this time and on the assumption that disabling sickness will not occur when the ERD is

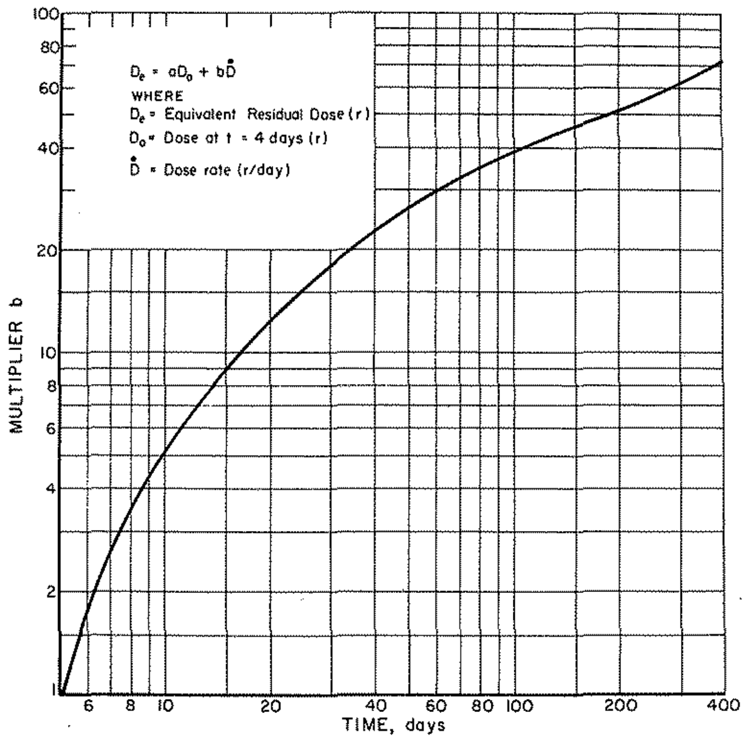

FIG. IIb.—Multiplier for protracted dose rate, to be used in calculation of ERD at any time.

less than 200 r. However, when protracted exposure exceeds 1.5 r/day, an ERD in excess of 200 r can be anticipated at some time less than 1 year, depending on the size of the initial brief dose.

It is apparent that protracted exposure should not exceed an average value of about 1.5 r/day and preferably should not exceed 1 r/day if the anticipated duration of exposure is at least 1 year. It should be noted that the daily exposure can be regulated by adjusting the time spent <u>in</u> and <u>out</u> of shelter.

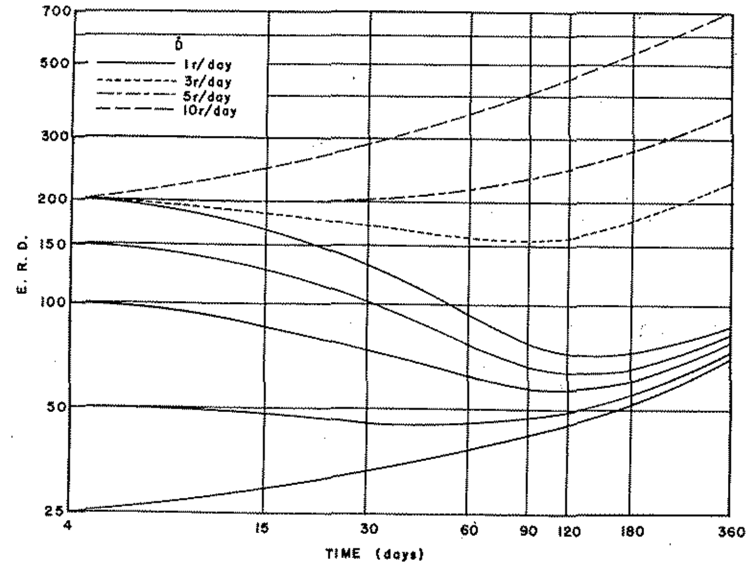

FIG. IIc.—Equivalent Residual Dose (ERD) at times up to 1 year after combined brief and protracted exposure. It is assumed that the brief exposure dose ended on the fourth day, at which time ERD equals accumulated exposure dose. The curves demonstrate the influence of recovery from the initial brief dose and from protracted exposure at a constant dose rate.

APPENDIX III

Empirical Relationships between Contamination and Skin Dose

The significance of skin contamination depends on the contamination density and the time of contact. This can be described by the quantity "accumulated contamination density" and expressed by the unit μc-hr/cm^2. The quantity "accumulated contamination density" includes both the preceding factors and hence can be employed as a measure of hazard of skin irradiation due to fallout. The expression μc-hr/cm^2 implies that it makes no difference whether an exposure of 200 μc-hr/cm^2 results from a contamination of 200 μc/cm^2 in contact with the skin for 1 hour or 20 μc/cm^2 in contact for 10 hours, etc.

The contamination density of the fallout field can be estimated from a measurement of the gamma-ray dose rate made 3 feet above the surface of the ground. The approximate relationship is that 1.0 μc/cm^2 = 0.1 r/hr. To a very rough approximation, for short periods of time (days), the beta-ray dose to the skin, in rads, resulting from fallout material in direct contact with the skin is about 50 times the accumulated gamma-ray exposure dose expressed in roentgens. Since skin injury from fallout material in direct contact with the skin can be significant when the dose exceeds approximately 1,000 rads, it is seen that this could be produced by an accumulated contamination density of 200 μc-hr/cm^2. Such a skin dose could occur in a fallout field where the measured accumulated gamma-ray exposure dose is 20 r.

Another very rough empirical relationship is as follows: The beta-ray dose delivered by fission products on the skin will be 5 rads/hr when the surface contamination density on the ground is 1 μc/cm^2.

Submitted for the National Committee on Radiation Protection and Measurements.

Lauriston S. Taylor, Chairman

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