REPORT NO. 1

background material for the development of radiation protection standards

May 13, 1960

Staff Report of the

FEDERAL RADIATION COUNCIL

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SECTION 1.—INTRODUCTION

1.1 It was recognized soon after discovery of x-rays that exposure to large amounts of ionizing radiation can produce deleterious effects on the human body so exposed. More recently, because of increased scientific knowledge and widespread use of radiation, additional attention has been directed to the possible effects of lower levels of radiation on future generations. Various scientific bodies have made recommendations to limit the irradiation of the human body. Probably the oldest of such scientific bodies are the International Commission on Radiological Protection (ICRP) and the U. S. National Committee on Radiation Protection and Measurements (NCRP). Initially, these bodies were interested primarily in the irradiation of those exposed occupationally, but recently they have been concerned with those who are non-occupationally exposed.

1.2 The ICRP was formed in 1928 under the auspices of the International Congress of Radiology. It is now a Commission of the International Society of Radiology. This Commission has published recommendations about every three years except for the period 1938-49.

1.3 The NCRP was initially organized as the "Advisory Committee on X-ray and Radium Protection." The initial membership included representatives from the medical societies, x-ray equipment manufacturers, and the National Bureau of Standards. After the reorganization in 1946, the name was changed to the National Committee on Radiation Protection and Measurements, and additional representatives from other organizations having scientific interest in the field were included. The recommendations of this group have generally been published as National Bureau of Standards handbooks. Since 1947, 15 such handbooks have been made available on different aspects of the protection problem.

1.4 In 1956, the National Academy of Sciences-National Research Council published reports of its Committees on the Biological Effects of Atomic Radiation. For genetic protection this group recommended a maximum gonadal dose up to age 30 both for individual radiation workers and for the entire population. These committees published a revised report in 1960.

1.5 The recommendations of the NCRP, ICRP, and NAS-NRC are in rather close agreement. The recommendations of the NCRP have received wide acceptance in the United States.

1.6 In 1955, The United Nations established a Scientific Committee on The Effects of Atomic Radiation (UNSCEAR). The report of this group (UNSCEAR, 1958) summarized the current knowledge on effects of radiation exposure and on human exposure levels. The report also contained predictions on exposures from testing of nuclear devices under various assumptions.

1.7 The Joint Committee on Atomic Energy of the Congress held public hearings in 1957 on "The Nature of Radioactive Fallout and Its Effects on Man." The same committee held hearings in 1959 on "Industrial Radioactive Waste Disposal;" on "Employee Radiation Hazards and Workman's Compensation;" on "Fallout from Nuclear Weapons Tests;" and on "Biological and Environmental Effects of Nuclear War." In all these hearings, questions of the biological effects of radiation and of protection against excessive exposure to radiation received attention.

1.8 The Federal Radiation Council was formed in 1959 (Public Law 86-373) to provide a Federal policy on human radiation exposure. A major function of the Council is to ". . . advise the President with respect to radiation matters, directly or indirectly affecting health, including guidance for all Federal agencies in the formulation of radiation standards and in the establishment and execution of programs of cooperation with States . . . ." This staff report is a first step in carrying out this responsibility. As knowledge of the biological effects of radiation increases, and as factors making exposure to radiation desirable undergo change, modifications and amplifications of the recommendations of this staff report probably will be required.

Scope

1.9 This staff report seeks to provide some of the required radiation protection recommendations. These recommendations are of an interim nature. Periodic review will be necessary to incorporate new information as it develops. This staff report includes recommendations for additional research which will provide a firmer basis for the formulation of radiation standards.

1.10 Only peacetime uses of radiation which might affect the exposure of the civilian population are considered at this time. The staff report also does not consider the effects on the population arising from major nuclear accidents. Only that portion of the knowledge of the biological effects of radiation that is significant for setting radiation protection standards is considered. Published information by the groups indicated above is summarized in this staff report; details may be found in the original reports.

1.11 Certain of the classes of radiation sources are now regulated by various Federal agencies. There are some which are not so regulated but which should be considered as aspects of the overall exposure of the population to radiation. Therefore, this staff report will consider exposure of the population from all sources except those excluded above.

Preparation of the Staff Report

1.12 In preparation of this staff report, a series of meetings was arranged with staff members of various Federal agencies concerned with radiation protection. The objectives of this first phase in the preparation were (1) to determine the problems unique to these agencies; (2) to define problem areas not adequately covered by current radiation protection recommendations of the National Committee on Radiation Protection and Measurements or the National Academy of Sciences; and (3) to discuss the implications of the above recommendations.

1.13 A second phase in the preparation of this staff report consisted of a series of consultations with Governmental and nongovernmental scientists in the various fields involved in the development of radiation protection standards. The purposes of these consultations were (1) to discuss the bases upon which recommendations on radiation protection standards are formulated; (2) to obtain the most up-to-date information on the biological effects of radiation; and (3) to elucidate some of the physical and chemical problems involved in the establishment and implementation of radiation protection standards.

1.14 These consultations and the reports of the groups indicated above provided a basis for the present staff report.

Definitions[1]

1.15 The activity of a radioactive source is the number of nuclear disintegrations of the source per unit of time. The unit of activity is the curie. The weight of a radionuclide corresponding to one curie is directly proportional to the half-life and to the atomic weight of the nuclide. For example, uranium-235 with a half life of 7.07×10^8 years requires about 4.65×10^5 grams to obtain an activity of one curie. The mass-activity relationship for iodine-131 with a half life of 8.0 days is about 8.05×10^{-6} grams to produce a curie.

1.16 Any biological effect produced by radiation depends on an absorption of energy from the radiation. For many years the roentgen (r)[1] has been used as a measure of x- and gamma-ray absorption in body tissue. Conceptually, the roentgen is only a measure of the ability of x- or gamma-rays to produce ionization in air and not of the absorption of these rays in tissue. More recently (ICRU H62, 1957), the absorbed dose of any radiation has been defined as "the energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest." The unit of absorbed dose is the rad. However, under most conditions and to the accuracy required for radiation protection purposes, the number of roentgens is numerically equal to the number of rads in soft tissues.[2]

[1]For detailed definitions see ICRU, H62, 1957.

[2]For the accuracy of this approximation and the conditions for its applicability, see the International Commission Radiological Units (ICRU) Report (1957).

1.17 The same absorbed dose of different kinds of radiation does not, in general, produce the same biological effect. Different kinds of radiation have a different relative biological effectiveness (RBE). It is well known that the RBE for a particular kind of radiation may be dependent upon such factors as the specific biological effect under consideration, the tissue irradiated, the radiation dose, and the rate at which it is delivered. Recommendations on radiation protection have generally assumed a specific RBE for each kind of radiation.[3] The RBE dose is equal numerically to the product of the dose in rads and an agreed conventional value of the relative biological effectiveness. The unit of RBE dose is the rem, considered to be that dose which is biologically equivalent to one roentgen of x- or gamma-radiation. For example, one rad of neutrons is conventionally considered to be equivalent to 10 roentgens of gamma radiation, and this equivalence is expressed by saying that the RBE dose is 10 rem. However, it has been found experimentally that the same RBE dose of different radiation sources in the bone does not always produce the same biological effect. A numerical factor called the relative damage factor is introduced to take care of this difference. Thus, in the case of bone, the biological effect is represented by the product of the RBE dose and the relative damage factor.

1.18 Radiation Protection Guide (RPG) is the radiation dose which should not be exceeded without careful consideration of the reasons for doing so; every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable.

1.19 Radioactivity Concentration Guide (RCG) is the concentration of radioactivity in the environment which is determined to result in whole body or organ doses equal to the Radiation Protection Guide.

Contents of the Staff Report

1.20 The following sections of this staff report provide information on human exposure from radiation sources, the present state of our knowledge on the genetic and somatic effects of radiation, the problems of formulating radiation protection standards from available scientific data, the basic and derived radiation protection guides, recommendations for further work by the Federal Radiation Council, and indications as to areas in which research is needed in order to fill gaps in our basic knowledge.

[3]Currently used values of RBE (relative to x-rays) are one for x-rays, gamma rays and electrons, 10 for neutrons and protons up to 10 Mev, and alpha particles, and 20 for heavy recoil nuclei. These are for chronic irradiation and should be used only for protection purposes.

SECTION II.—KNOWLEDGE OF RADIATION EFFECTS

Introduction

2.1 This section includes general summaries of knowledge of the biological effects of ionizing radiation on animals and man particularly pertinent to the problem of defining radiation protection standards. As noted in Section I (paragraph 1.13), this staff report was developed following a series of consultations with scientists who provided recent information on the genetic and somatic effects of radiation. The consultations included the experimental evidence in animals and the observations on humans, as well as the assumptions, hypotheses, and unknowns in the relationships of radiation dose and effects.

Definitions of General Biological Factors

2.2 Radiation exposure can be described in terms of the part of the body exposed, the total dose delivered, the dose rate, and the duration of the exposure. Acute exposure is usually considered an exposure to a single event of irradiation or a series of events in a short period of time. Continuous or fractionated exposures over a long period of time are considered chronic exposures.

2.3 Acute exposure can result in both immediate and delayed biological effects. Chronic exposure is usually considered to produce only delayed effects. The acute radiation syndrome will not be discussed in detail since it is applicable primarily to accidental or emergency exposures. The literature documents this effect (refer to Table 2.1).

2.4 The available data describing immediate effects on humans include:

(1) Medical data on effects following the therapeutic use of external sources such as x-rays, and of radionuclides such as radium, iodine, etc.;

(2) Occupational data on exposure of radiologists, cyclotron workers, and workers in nuclear industry as a result of certain accidents; and

(3) Population observations on atomic bomb survivors and on persons irradiated by heavy fallout in the vicinity of the Marshall Islands.

2.5 Most delayed effects, in man, are inferred from consideration of experimental knowledge in animals, from available epidemiological statistical observations, and from a limited number of medical and industrial case observations. Delayed effects are those effects observable at some time following exposure. The effects considered are: (1) genetic effects; and (2) somatic effects, including the appearance of leukemia, skin changes, precancerous lesions, neoplasms, cataracts, changes in the life span, and effects on growth and development. The delayed effects produced by ionizing radiation in an individual are not unique to radiation and are for the most part indistinguishable from those pathological conditions normally present in the population and which may be induced by other causes.

2.6 External radiation exposure refers to that exposure resulting from sources outside the body. Classifications of external radiation exposure are made on the basis of the portions of the body irradiated: whole body or partial body.

2.7 Internal radiation exposure is that which comes from radioactive materials incorporated within the body following their ingestion, inhalation, injection, or absorption.

2.8 A critical organ is defined as that organ of the body whose damage by a given radiation source results in the greatest impairment to the body. Criteria appropriate to the determination of critical organs for external or internal exposure are: (1) the radiosensitivity of the organ, i.e., the organ damaged by the lowest dose; (2) the essentialness or indispensability of

TABLE 2.1

SUMMARY OF EFFECTS RESULTING FROM ACUTE WHOLE BODY EXTERNAL EXPOSURE OF RADIATION TO MAN[1]

0-25 r	25-100 r	100-200 r	200-300 r	300-600 r	600 or more
No detectable clinical effects.	Slight transient reductions in lymphocytes and neutrophils.	Nausea and fatigue, with possible vomiting above 125 r.	Nausea and vomiting on first day.	Nausea, vomiting and diarrhea in first few hours.	Nausea, vomiting and diarrhea in first few hours.
			Latent period up to two weeks or perhaps longer.	Latent period with no definite symptoms, perhaps as long as one week.	Short latent period with no definite symptoms in some cases during first week.
Delayed effects may occur.	Disabling sickness not common, exposed individuals should be able to proceed with usual duties.	Reduction in lymphocytes and neutrophils with delayed recovery.	Following latent period symptoms appear but are not severe: loss of appetite, and general malaise, sore throat, pallor, petecheae, diarrhea, moderate emaciation.	Epilation, loss of appetite, general malaise, and fever during second week, followed by hemorrhage, purpura, petecheae, inflammation of mouth and throat, diarrhea, and emaciation in the third week.	Diarrhea, hemorrhage, purpura, inflammation of mouth and throat, fever toward end of first week.
	Delayed effects possible, but serious effects on average individual very improbable.	Delayed effects may shorten life expectancy in the order of one per cent.	Recovery likely in about 3 months unless complicated by poor previous health, superimposed injuries or infections.	Some deaths in 2 to 6 weeks. Possible eventual death to 50% of the exposed individuals for about 450 roentgens.	Rapid emaciation and death as early as the second week with possible eventual death of up to 100% of exposed individuals.

[1]Adapted from "The Effects of Nuclear Weapons," U. S. Government Printing Office, 1957.

the organ to the well-being of the entire body; (3) the organ that accumulates the greatest concentration of the radioactive material; and (4) the organ damaged by the radionuclide enroute into, through, or out of the body. For a given situation, determination of the criteria chosen for internal emitters is subject to judgment based on various factors: physical (particle size), chemical (solubility; the compound form of a given chemical element), ecological (the environmental balance of calcium or iodine) and physiological (differential uptake by age and the metabolic condition of the organism).

2.9 On the basis of comparisons with known effects of x-rays in humans and animals, radioisotope experiments in animals, and the radium and other radioisotope observations in man, certain organs in the body appear to be the critical organs under various conditions of irradiation. These organs, and examples of the delayed effect of irradiation upon these organs are: (1) gonads: genetic alterations; (2) bone marrow and other blood forming organs: the leukemias, aplastic anemia; (3) whole body: life span shortening; (4) single organs (bone, skin, thyroid, etc.): neoplasms, and other pathological effects; and, (5) the lens of the eye: cataracts. These are the effects ordinarily considered when assigning guides for external and internal exposure.

2.10 A body burden of a radionuclide is that amount present in the body. The organ burden is the amount present in an organ.

2.11 Multiple exposures may occur from diverse sources, e.g., from several sites of deposition and from several routes of entry into the body. Sources may be external or internal. An external source may irradiate the whole body or a portion of the body. An internal source or sources may produce radiation exposure in several ways: (1) a single radionuclide may produce whole body exposure or a single organ exposure; or (2) single nuclides may affect different body organs simultaneously; or lastly, (3) multiple radionuclides may be absorbed thereby producing whole body, or single, or several organ exposures.

Biological Variability

2.12 Variations of effect with age depend upon metabolic, cellular, and organ differences. Some factors of significance are:

(1) Radiation sensitivity of a cell in terms of chromosomal aberration depends on the stage of mitosis when radiation is delivered. Damage becomes manifest when cell division takes place; the more divisions that occur, the greater the probability of manifestation.

(2) During fetal life there is a greater sensitivity to radiation and the median lethal dose (LD_{50}) of fetuses is less than that of adults. After birth, in certain strains of mice the radiosensitivity decreases until maturity is reached, and then remains relatively constant until late in life when radiosensitivity again rises sharply.

(3) Gross malformations may result from small amounts of radiation delivered to the developing embryo. The production of clinically evident malformations in fetal life depends on the stage of embryonic organ development when the radiation is delivered.

2.13 Although few data are available on human populations it is presumed from the analogy of other stresses that undernourishment and strain may affect radiosensitivity. Anemia renders mice more sensitive to radiation. However, from the evidence on radiobiological studies in tissue culture, and on the induction of mutations and biochemical effects, it has been shown that a reduction in oxygen tension produces a lowered response to radiation.

2.14 There is a scarcity of information on the effect produced by the simultaneous presence of bone-seeking nuclides (radium, strontium) and bone infection or bone conditions in which the mineral states are altered due to aging.

2.15 The minimum doses causing biological effects detectable by current methods differ among species. However, for most mammals the LD_{50} dose varies by less than an order of magnitude.[1] Comparison of genetic effects between the fruit fly and the mouse can be cited. The x-ray induced mutation rate per r per average gene locus varies by a factor of 15 between fruit fly and mouse. For mouse spermatogonia the sensitivity of the mutation rate per locus (at 90 r per min.) from least to most sensitive locus may vary by a factor of 30; while in the fruit fly the specific locus sensitivity varies by a factor of two. Our ability to extrapolate confidently the data from animal experience to man depends on whether there is sufficient evidence of similarity between humans and the experimental animals.

2.16 Within an individual, the range of tissue sensitivity varies by more than an order of magnitude from the more sensitive (blood forming organs) to the more resistant (the adult nervous system).

2.17 The apparent sensitivity of a tissue to damage depends on the index of measurement used, e.g., the biochemical effect, the mitotic effect, the cellular effect, or states of tissue derangement, tumor production, or life span changes. As examples, (1) for changes in the lens of the eye, one may measure the clinical appearance of cataracts years after radiation injury, or one may measure the immediate biochemical changes; (2) lymphocyte damage may by measured

[1]The term, an order of magnitude, as used in this staff report refers to a factor of ten.

by the reduction in the number of lymphocytes, or by the structural changes in the cell nucleus, or by the chemical change in nuclear DNA content; and (3) the effect on bone marrow may be measured by the appearance of immature cells in the blood stream or by the rate and amount of Fe-59 incorporated in the cells.

2.18 In an individual adult it is difficult or in some cases impossible to detect effects from a single external exposure of less than 25 to 50 r, and from continuing exposure to levels even about two orders of magnitude greater than natural background. It should be noted, however, that changes in the nucleus of lymphocytes have been described in some adult radiation workers after two weeks of exposure to levels as low as 0.20 r per week.

2.19 Man's sensitivity to radiation depends on his age at the time of exposure. Considering his long life, the time periods of importance are: for genetic considerations, the interval from conception to the end of the reproductive period; and for somatic effects, the total lifetime during which delayed effects may become manifest.

(1) Embryonic neuroblasts in vitro are sensitive to a dose of radiation of orders of magnitude smaller than the dose which kills adult nerve cells.

(2) In fetal organ systems, effects (e.g., delayed effects on blood forming tissues) may be evident with 2-10 r acute exposure, and skeletal effects with 24 r.

(3) The child's thyroid is more sensitive than the adult thyroid. Cancer of the thyroid has been observed in children after an acute external exposure of approximately 150 r. In adults the same effect has been observed only after exposures of more than several hundred r.

(4) A study of the differential sensitivity for induction of skin tumors by x-ray (used in the treatment of hemangiomas) showed that children were 3-4 times more sensitive than adults.

(5) In adults, the presence of disease states may be correlated with the later appearance of neoplasms, apart from the effects of radiation. This has been reported in ankylosing spondylitics who later developed leukemia.

2.20 In addition to differential sensitivity there are important factors of differential uptake between adults and children. Some of these are:

(1) The rate of deposition of skeletal calcium and the fractions of equilibrium Sr-90/Ca ratio for accretion and for remodeling of bone are each a complex function of age; each may vary by a factor of at least 10 from newborn to age twenty.

(2) The uptake of iodine per gram of tissue by the normally functioning thyroid gland differs widely between children and adults.

(3) Different age groups are exposed to different environmental radiation conditions. For example, because of differences in dietary intake an infant may be exposed to different total amounts of Sr-90 radiation than an adult.

2.21 There is a current definition for the "average" adult--"Standard Man." The "Standard Man" is defined in such terms as organ size, distribution of elements in the body organs, fluid intake and excretion, and air balance. Each of these factors differs between adults and children, and also differs among various age groups of children. Therefore, there is a need for a comparable definition of "Standard Children" to be used in developing Radioactivity Concentration Guides.

Dose-Effect Relations for Genetic and Somatic Effects

2.22 Among the possible dose-effect relationships at least three possibilities have been considered in the literature: (1) a linear, no threshold concept; (2) a nonlinear, no threshold concept; and (3) a nonlinear, threshold concept. Among the parameters which must be considered in the relationships are the total dose, the dose rate, the biochemical or clinical manifestation of effect, and the period of time in which the effect becomes manifest.

2.23 The evidence for linearity and no threshold for induction of mutations in the genetic material is based on work with fruit flies and mice. The method consists in the scoring of the occurrence of specific traits in progeny of irradiated animals. In studying irradiated males, the experimenter can determine the genetic manifestations in the progeny corresponding to the stages of development of spermatogonia and spermatozoa in the parent. This can be accomplished by selecting suitable time intervals between irradiation and mating. Experimentally one measures visible traits in the offspring (such as coat color changes in the mouse or failure of pupal development in the fruit fly). These traits are then attributed to specific gene mutations in the parent germ cell. The effect is therefore considered to be directly proportional to the number of genetic changes induced in the parental germ cell. It is well demonstrated that the curve showing effect against dose in experimental animals is linear within the range of 37 r to 1,000 r total acute dose, and geneticists believe that there is no threshold for the genetic effect. The finding of a dose-rate dependence effect (chronic exposure is approximately one-fourth as effective in inducing mutations as is acute exposure) probably represents partial recovery at low dose-rates and does not conflict with the no threshold concept.

2.24 For somatic effects, unlike genetic mutation effects, there is no general agreement among scientists on the dose-effect relationships. It is known, for example, that the nature of the dose-response curve can be altered drastically by changes in the external environment of the organism. In addition, although radiation may be the initiating event, there may be other promoting factors operating before the manifestations are evident. Such factors mentioned in the literature include cocarcinogens: hormones, chemicals, and viruses.

2.25 Because of the complexities of animals and man, there may be many mechanisms by which radiation produces effects. One of the mechanisms may be the induction of a primary effect by radiation which, after a sequence of secondary events over a period of time, leads to a clinical manifestation such as neoplasia. In this hypothesis, the induction of the primary effect could be consistent with a linear no threshold concept of dose-effect relationship, yet the successive manifestations of the damage could be nonlinear and not consistent with a threshold concept. Therefore, in the case of neoplasia, the demonstration of linearity or nonlinearity for the gross effect does not predict the presence or absence of a threshold dose for the primary insult.

2.26 There are some somatic effects in animals which do not support a linear no threshold concept (e.g., acute mortality; splenic, thymic and testicular atrophy, incidence of lens opacity, duration of depression of mitotic activity, and incidence of heterologous tumor implants). However, the experiments demonstrating these effects were not performed primarily to examine threshold theory and were done at high dose ranges above 100 r. Considering the diversity of results in different species of animals, extrapolations to man for these effects at low doses should be made with caution.

2.27 In man, the chief evidence for a linear dose-effect relationship for somatic effects comes from some of the leukemia studies (see Table 2.2). Data are available for acute exposures above 50 rads in adults. Predictions of the incidence of leukemia in the general population per rad of exposure have been made by extrapolations from these data. Certain of these predictions have involved the assumption that the occurrence of radiation-induced leukemia per rad will remain constant for the life of the population, the assumption of no difference among effects of irradiation of various parts of the body and the assumption of a constant probability of occurrence of leukemia per rad of acute and chronic exposure. There is no direct evidence that justifies extrapolation from the condition of acute exposure to one of a low dose chronic external exposure, or to the radiation from internal emitters.

2.28 In summary, the evidence is insufficient to prove either the hypothesis of a damage threshold or the hypothesis of no threshold in man at low doses. Depending on the assumptions used, forceful arguments can be made either way. It is therefore prudent to adopt the working principle that radiation exposure be kept to the lowest practical amount.

Genetic Effects

2.29 The following working assumptions have been derived from the evidence considered in this staff report: (1) radiation induced mutations, at any given dose rate, increase in direct

linear proportion to the genetically significant dose;[2] (2) mutations, once completed, are irreparable; (3) almost all the observed effects of mutations are harmful; (4) radiation-induced mutations are, in general, similar to naturally occurring mutations; and, (5) there is no known threshold dose below which some effect may not occur.

2.30 The linearity is established in fruit flies down to 25 r and is confirmed in mouse spermatogonia down to 37 r, but there is no direct evidence for linearity below these doses. Although the studies in animals do not involve a period comparable to the 30-year period of chronic irradiation in humans, the hypothesis used in this staff report is that the mutations induced by small dose rates of radiation to human reproductive cells are cumulative over long periods of time. Under this assumption, irradiation of the whole population from any source is expected to have genetic consequences.

2.31 In addition to genetic effects in the progeny of an exposed individual, attention must be given to the total genetic effect on the population. Within the working assumptions above, the total genetic load is independent of the distribution of the exposure within the population. Therefore, when radiation protection standards are established for large numbers of exposed persons, limitations may be imposed by considerations of population genetics (the effects on population as a whole).

2.32 Major areas of uncertainty in genetic information for man, with regard to both population and individual genetics, are the estimations of: the spontaneous and induced mutation rates; the genetic load of mutations; the influence of man-made factors (mortality reduction brought about by health protection, for example) operative in natural selection; and the influence of synergism of gene interaction.

2.33 Formulation of radiation protection standards has been based in part on estimates of genetic hazards to man. These in turn have been based chiefly on data from mice and from acute rather than chronic irradiation. Results of recent experiments considered pertinent to the evaluation of genetic effects are:

(1) The genetic effects under some radiation conditions may not be as great as those estimated from the mutation rates obtained with acute irradiation. It has been shown in mice that fewer specific locus mutations are produced in spermatogonia and oocytes by a low dose rate (chronic gamma radiation at 90 r per week) than by a high dose rate (acute irradiation at 90 r per minute) for the same total accumulated dose above 100 r. A similar effect has been reported for sex-linked lethal mutations in the oogonia of fruit flies. The number of mutations induced in spermatogonia by chronic irradiation is smaller (about one-fourth) than that induced by acute irradiation.

(2) Studies being planned may define quantitatively the dose-effect relationship with fractionated, low doses delivered at high dose rates. These data may be of direct significance to medical practice using fluoroscopy and radiography.

(3) Life shortening has been demonstrated in the offspring of male mice irradiated at high doses.

(4) Radiation doses of 25 r appear to produce chromosomal breakage in human cells grown in tissue culture.

Items (1) and (2) above indicate that in the preparation of radiation protection standards based on the genetic effects, consideration should be given to dose rate as well as total dose.

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[2]The genetically significant dose to the individual is considered to be the accumulated dose to the gonads weighted by a factor for the future number of children to be conceived by the irradiated individual. The genetically significant dose for the population is defined as the dose which, if received by every member of the population, would be expected to produce the same total genetic injury to the population as do the actual gonad doses received by the various individuals.

Leukemia

2.34 Information useful for study of the risk of leukemia among exposed persons is based on experimental data on animals, some observations on humans, and the rise in crude leukemia mortality rates observed in many countries. There is more information available on the correlation between radiation exposure and leukemia incidence in man than there is for other radiation effects.

2.35 Most of the reported investigations indicate that the incidence of leukemia among irradiated persons increases with the exposure dose. A definitely increased incidence of leukemia occurs after one large whole body dose or a large accumulated dose. The available evidence applicable to the general population under the assumptions listed in paragraph 2.27 indicates a linear correlation of dose to incidence down to about 50 rads of whole body acute exposure. The specific findings in other studies vary with the type of exposure and are speculative at lower doses. There have been reports that, during prenatal life, fetal doses as low as 2-10 r may double the incidence of leukemia, although other studies have not confirmed this finding. Prenatal exposure may be quite different from exposure of adults and there is no evidence that these low dose levels may be effective later in life. There is also no satisfactory evidence that chronic lymphatic leukemia is produced by radiation although this is the form of leukemia primarily responsible for the rising crude leukemia rate in the general population.

2.36 Past studies of leukemia-radiation correlations in human populations have limitations imposed by retrospective epidemiological techniques as well as factors inherent in the nature of leukemia. Epidemiological techniques which are retrospective in type are limited by the:

(1) difficulty of determination of the radiation dose;

(2) absence of uniform radiation recording methods;

(3) difficulty of associating medical and vital statistical records: i.e., such studies introduce biases inherent in the techniques of interview, questionnaire, or manual searching;

(4) statistical selection of cases which may be weighted with those cases having a disease related in some way to leukemia; and

(5) the fact that the numbers of persons in the population groups studied are usually small.

2.37 The following factors produce difficulties in the evaluation of the findings on possible radiation produced leukemia:

(1) Although leukemia has the advantage of the use of simpler procedures for the diagnosis of the disease than are available for other neoplastic diseases, it has the disadvantage that the classification of various types of leukemia is subject to debate. It is thus difficult to compare statistics of different origins.

(2) The hematological effects such as are seen in leukemia can also be observed in other diseases which may or may not be radiation induced.

(3) Leukemia ascribed to radiation cannot be distinguished from leukemia due to other causes.

(4) Leukemia in humans is a rare disease whose crude annual incidence in the population-at-large is about 5 per 100,000 persons.

(5) The various forms of leukemia have different clinical courses and the relative incidence of cytologic types varies with age. Not all the various forms of leukemia can be placed in one category since it does not appear that the chronic lymphatic form may be induced by radiation.

2.38 Considerations of the above factors require that epidemiological studies include large samples of exposed subjects, provide mechanisms for follow-up over long periods of time, provide adequate control groups, and provide ascertainable exposure and outcome.

2.39 Conclusions drawn from the studies listed in Table 2.2, indicate that:

(1) Under certain conditions, there is a clear association between leukemia and prior radiation exposure. This association has been demonstrated only where the exposures are high. The effect may be discerned at doses of the order of several thousand r for prolonged intermittent exposure over many years in normal adults; or, doses of the order of 500 r for bone marrow exposure in adult males with pre-existing disease; or, doses of the order of 50-100 r for acute whole body exposure in a general population of all ages; or at acute dose possibly as low as 2-10 r to the fetus;

(2) Long follow-up periods are required to assess cancer experience following irradiation.

(3) Little data exist on leukemia incidence among women exposed to therapeutic doses of radiation from radium or x-rays;

(4) It is unlikely that retrospective studies will definitely solve the question of the shape of the dose-response curve at low levels of exposure or the existence of a threshold. Additional retrospective studies on population groups receiving high doses of radiation may provide refined quantitative knowledge. There are only a few prospective studies reported that can provide information on both the quantitative and qualitative effects of chronic low doses received over many years;

(5) The risk of any one individual developing leukemia is small even with relatively large doses. However, when large populations are exposed, the absolute number of people affected may be considerable.

2.40 The leukemogenic effect of internally deposited isotopes requires special mention.

Strontium: We have no documented evidence that bone depositions of strontium in humans have produced leukemia. Statements that radiostrontium is leukemogenic are based solely upon studies in mice. Since leukemia is a common disease spontaneously occurring in certain strains of mice, one cannot accept this observation as necessarily applicable to man.

Thorium: Only a few cases of leukemia following thorium injections for medical diagnosis have been reported in the literature. The leukemias have occurred with latent periods up to 20 years. However, the dose calculations for irradiation of the bone are complicated by the presence of thorium daughters.

Radium: No cases of leukemia have been reported in those persons who have had radium deposited in their bones, even though some persons developed bone cancers. This is not unexpected in view of the fact that radium deposited in bones results in a relatively small dose to the bone marrow.

Iodine: Only a few cases of leukemia have been reported in patients receiving iodine-131 for the medical treatment of hyperthyroidism and cancer of the thyroid. It would seem that well planned large population studies on persons who received radioiodine medically would contribute to the knowledge of the leukemogenic and carcinogenic effect at the levels used.

2.41 The possibility of the detection of low doses of radiation by hematological techniques is deserving of high priority. The most sensitive indicator available at present may be the counting of binucleated lymphocytes, but the technique is not now practical for wide applications because of the need to examine large numbers of cells on hematology slides. The development of practical electronic devices to screen these cytologic blood specimens should be encouraged. The prognostic significance of the observations of morphological changes in the lymphocytes will be elucidated by long term follow-up of selected study and control groups.

Other Neoplasms and Premalignant Changes

2.42 Clinical evidence indicates that irradiation in a sufficient amount to most parts of the body may produce cancer as a delayed effect although no inference of an incidence-dose relationship should be drawn. Some of the evidence in humans is based on:

(1) skin cancers among radiologists in the early history of the use of x-ray;

(2) thyroid cancers in children irradiated in the neck region;

(3) Leukemia among children who were exposed in utero to x-ray for pelvimetry of the mother;

(4) Bone sarcomas in radium dial painters and other persons exposed to radium-226;

(5) Liver sarcomas in medical patients given thorotrast; and

(6) Bronchogenic cancer in miners occupationally exposed to radon and its daughters.

2.43 The bulk of the evidence lies in the work done on animals with external whole and partial body doses, as well as with internally absorbed radionuclides. Both benign and malignant lesions have been produced, although the evidence is incomplete and there is no simple relationship between carcinogenesis and dose. Mice are more sensitive to all modalities of radiation exposure than man for the induction of skin and ovarian tumors and leukemia.

TABLE 2.2

TYPES OF STUDIES THAT HAVE BEEN DONE IN HUMANS ON LEUKEMIA AND RADIATION

I. Occupational

1. Cases not reported in the literature.
2. Scattered reports in the literature.
3. Radiologists.
4. Uranium miners.

II. Therapeutic and Diagnostic

1. Children receiving partial body exposure to x-rays.
   a. Infants treated for thymus gland enlargement.
   b. Infants similarly treated who had normal size thymus glands.
   c. Children treated for pertussis and lymphoid hyperplasia.
   d. Children treated for other benign conditions of many different types.
   e. Children treated for neuroblastoma.

2. Adults
   a. Patients with ankylosing spondylitis given x-ray treatment to the spine.
   b. Radiologists receiving partial body x-ray radiation over many years.
   c. Patients treated for hyperthyroidism with x-ray; and radioiodine.
   d. Patients treated for polycythemia with radiophosphorus.

3. Prenatal

   Maternal prenatal exposure to diagnostic doses of x-rays.

III. General Population

Japanese people who received whole body irradiation from A-bomb explosion.

IV. Internal Emitters

1. Thorotrast
2. Radium
3. Iodine
4. Phosphorus

2.44 It is pertinent to the discussion of a threshold dose or dose rate dependence for carcinogenesis to describe two theories of radiation carcinogenesis: the direct somatic mutation effect and the theory of indirect effect.

2.45 The direct theory postulates that the incidence of tumors induced by radiation in a population is proportional to the dose. This theory states, by direct analogy with genetic theory, that the somatic cell may incur chromosomal changes which become evident on cell division and lead to a neoplastic change. So far it is impossible to test this on human populations. Animal experiments show that the effect is much more complicated. The theory of indirect effect considers that there are tissue and hormonal factors which mediate the occurrence and site of development of tumors following irradiation.

2.46 The evidence bearing on the two theories may be summarized as:

(1) The long latent period for development of tumors may indicate that they develop only after a series of premalignant changes or states of tissue alteration have taken place. As yet unknown is the sequence of events and how the events are correlated with dose or dose rate. For example, the deposition of radium in bone may produce slight changes in the bone at lower levels, necrosis at increasing levels, and bone tumors at high levels.

(2) In man, the latent period for cancer induction by radiation is often from 10 to 20 years, although for leukemia the period may be from 5 to 10 years after a single whole body irradiation. For chronic exposure at low dose rates, it would appear that the latent period is longer.

(3) Tissue changes induced by radiation need not occur at the site of injury. There are indications that the critical factors may include responses of the whole body to the radiation, rather than the radiation effect upon a single cell exclusively; examples of this principle are:

(a) The primary cause of tumors such as mouse lymphomas or mouse ovarian and pituitary tumors may be disturbances of an endocrine gland.

(b) Mouse experiments how that shielding of a part of the body will prevent the appearance of radiation leukemia, or that shielding one ovary will prevent a tumor from developing in the other.

(c) Cells grown in tissue culture (where growth inhibitory factors which may be present in the body are lacking) have a tendency for malignant variance entirely apart from considerations of radiation. Under certain conditions, attempts to transplant a tumor to an animal are unsuccessful until the animal has developed an autogenous metastatic malignancy.

(d) The presence, in an animal or man, of a cancer is associated with an increased probability of occurrence of a second cancer, in a similar or other tissue.

2.47 At chronic low levels of radiation the combination of varying susceptibility with age and the long latent period for tumor induction complicates an analysis of dose-effect relationships. Experimental animals must be maintained for long periods of time and there must be large numbers of animals to achieve statistically significant results.

2.48 In man, the data seem to show that one must be exposed to relatively high external exposure levels to show a carcinogenic effect in certain tissues. For example, available information indicates that cancers have been observed in persons receiving doses in the range of 500 to 2,500 r to the skin. The thyroid carcinogenic dose has been shown to vary greatly with age and may be one of the most sensitive indices in children of the carcinogenic property of radiation.

Bone Tumors From Internal Emitters

2.49 The two sets of crucial data on the problem are the human radium experience and the animal experiments, now underway, on comparative toxicity of radium, strontium, plutonium, and thorium.

2.50 Historically, the evidence leading to the first establishment of a radium body burden limit, for occupational workers only, was based on physical data and a small amount of biomedical information on a few dozen adults. Summaries of new data on several hundred living persons have been reviewed for this report. Persons studied were workers who absorbed pure radium (or radium plus mesothorium and radiothorium) in the course of radium dial painting, or were patients treated medically with radium waters, or were persons drinking public water supplies relatively high in radium. The information permits the comparison of effect on bone with body burden estimates of radium-226-equivalent present after periods as much as 35 years of prolonged exposure. Present physical techniques of estimation of body burden are based on radon breath analysis, whole body gamma counting, excreta analysis, and the assay of teeth and bone. The complications of dosimetry in some of the dial painters arising from the presence of both radium and mesothorium are partially resolved, but the exact equivalance of radium to mesothorium is not well established.

2.51 The clinical evaluation of the living persons studied includes a history, physical examination, and radiographic and pathological studies. The criteria of effect are based on the differential diagnosis of x-ray evidence of bone changes, the presence of pathological fractures, bone tumors, changes in teeth or signs of other findings.[3] The period between exposure and observation of skeletal changes by x-ray examination is usually determined by the date of examination rather than the date of onset of skeletal changes. Rarely are serial radiographs available over a period during which the changes first appear. In other than special microradiographic studies, there is no evidence available of cellular or biochemical effects.

2.52 A major problem in evaluation of the hazard of radium exposure is the definition of a clinically significant effect. If clinically significant effect is defined in terms of significant injury to the person, it may include only the symptomatic factors which impair the person's daily living, energy or longevity (tumors and pathological fractures). If clinically significant effect is defined in terms of detectable changes, the index may be radiographic evidence discernable to a competent physician. In either case the changes indicate varying degrees of late effects and are observed after many years of exposure.

2.53 It can be hypothesized that, on a cellular level, the effect is linearly proportional to body burden. Gross demonstrable changes plotted against dose could follow a normal distribution even though the effect at the cellular level were linear.

2.54 In attempting to define effects which can be extrapolated to the general population the following unknowns are apparent:

(1) the sequence of events during the latent period, as a function of dose;

(2) the radiobiological effect on small volumes of tissue;

(3) the site of injury and the degree of recovery from injury;

(4) the elapsed period of time from cellular injury to the evidence of the effect and the possible interrelationships among bone osteitis, necrosis, pathological fracture, and bone tumors;

(5) the variance in biological sensitivity with age; also, the variance in bone physiology at all ages in humans, the structure of the organic matrix, the crystalline and vascular structure, and the differences in homogeneity of distribution of the bone seeking nuclides;

(6) the variations of body burden with time in the individual after a single or fractionated intake; more radium retention data are needed in humans to permit determination of body burdens at times less than the 35 years after initial intake;[4]

[3]The indices used are: absence or presence of x-ray evidence of localized areas of bone rarefaction, areas of increased density, abnormal trabecular pattern, severe aseptic necrosis, pathological fracture; abnormal tooth structure; sarcoma; carcinoma at other sites; leukemia; anemia.

[4]Some recent data suggest that, for oral intake of radium waters, the measured body burden of humans drinking the waters is about one-sixth of the body burden predicted by currently used biological models.

(7) information from large populations on the correlation between the average background body burden of radium and the natural population incidence of osteogenic sarcoma; and

(8) uncertainties in the RBE for alphas on chronic exposure.

2.55 There is no evidence to establish definitely the presence or absence of a threshold for the effects of radium deposition in bone. However, the first appearance of minimal radiographic changes in bones of adults exposed to radium occurs with a residual body burden (measured several decades after exposure) of the order of 0.2 microgram. Whether this effect is attributable to radium is in doubt because of the absence of matched age group controls. There seems to be no doubt that, at 0.5 microgram burden, changes in adult bones, shown by radiographs, are manifest in some individuals. Radiographic changes are always seen above 0.8 microgram, and there is agreement that bone tumors begin to occur at about a burden of 0.8 to 1.0 microgram. Teeth changes were noted in a young person with a body burden of 0.15 microgram. Within the limits of the time duration for the effect and the relatively small numbers of individuals studied, there is a range of radium body burdens within which any specific clinically significant effect occurs. The body burdens among individuals with a given effect appear to be statistically normally distributed. At increasing burdens the curve of body burden against effect follows a steeply rising slope. At body burdens below 0.1 microgram, which is the area of our interest, prediction is hazardous.

2.56 It would appear that current radium studies (among the groups described in paragraph 2.50) may have a maximum number of about 2,000 persons available for body burden measurements. These numbers may be insufficient on a statistical basis to assure extrapolation of the probability of occurrence of an effect to the general population. It remains to be demonstrated whether or not, on an individual basis, the diagnostic methods used on humans can show "damage" below 0.1 microgram. This is true even if one studies a larger number of individuals, particularly if the group is composed of children with differential sensitivity or of older persons with intercurrent infections or increased bone fragility. It is hoped that pertinent data on the question of threshold will be forthcoming from animal studies. There is suggestive evidence that the length of the latent period for the development of "clinically significant findings" may increase as the body burden decreases. If this be true, depending on the age of the animal, the latent period may be greater than the remaining lifetime of the animal.

2.57 With other bone seeking radionuclides there are not as extensive data in man on biological effects as for radium. Therefore, it has become the custom to relate the biological effects of other bone seeking radionuclides to those of radium. Evidence for the relationships has been obtained at high doses in animals. For example, mouse experiments showed the ratio of body burden of radiostrontium to radium for the same tumor induction to be approximately 10 to 1. However, newer biological data in man on the skeletal escape and excretion of the radium daughter radon require further adjustment in the ratio when it is applied to man. Although bone tumors have been produced by radiostrontium in animals, it should be noted that no cases of bone tumors have been demonstrated in man as due to strontium-90.

Life Span Shortening

2.58 Radiation exposure does not produce in the individual a pattern of effects specific to radiation. Life span shortening has been demonstrated in animals by comparisons of mean life span between exposed and nonexposed groups. This involves observations continued to death of the cohorts of the irradiated individuals while controlling the intercurrent factors which might affect the study groups.

2.59 The experimental evidences of radiation effect on life span in animals includes:

(1) Exposure of animals to chronic high doses, in general, decreases their life span. A plot of the percentage survival vs. time yields an S shaped curve in both the exposed group and the unexposed controls. The mean survival time, however, is shortened in the exposed group to the total dose. While the evidence is not conclusive, it appears that in mice the mean life span is lengthened at very low dose rates, at a total dose of about 100 r. However, in every piece of experimental evidence (except at about the 100 r level in animals described above) there is life span shortening at dosages above approximately 100-300 r total body dose. At such dosages the life span shortening in mice is in the order of 1 to 1.5 percent of total life

span per 100 r total dose. The evidence for linearity of the dose-effect curve in other species (dogs) rests on only a few animals and, again, at doses greater than 100 r. There is suggestive evidence that protracted doses above 200 r have a lesser effect than a single acute dose. For protracted radiation, in some experimental animals, it appears that there is some life shortening from the range of 200 to 1000 r, but that the chronic radiation is about 4 to 5 times less effective per r than a single very large dose. For radiations other than x- or gamma-rays the RBE for this effect is uncertain.

(2) A decrease in the median lethal dose is observed when pre-irradiated animals are exposed to a second course of irradiation in comparison to controls not previously irradiated. This decrease in the LD_{50} depends upon the elapsed time between first and second exposure.

2.60 The facts concerning acute injury and delayed effects described above might lead to the following assumptions; viz:

(1) The total injury produced by radiation varies linearly with the dose.

(2) Partial recovery from acute injury occurs, but an irreparable effect remains.

(3) Recovery from reparable injury is an exponential process. The recovery rate varies with the dose rate and whether the exposure is whole body or partial body. The exponential rate of recovery following acute exposure is the cumulative expression of the fact that different parts of the body repair at different rates.

(4) Irreparable injury is accumulated in proportion to the total dose. It may be measured by life shortening, or, for experimental purposes, by a reduction in the median lethal dose. Residual injury of irradiation occurs irrespective of the age of the animal when irradiation is begun.

2.61 Examination of the specific causes of death shows that the same causes of death, apart from tumors, occur generally in the same proportion but sooner in the irradiated than in the unirradiated individuals. It is to be noted that observations are sometimes made of some vascular impairment or accumulation of connective tissue, but these cannot be quantitated. Studies of performance tests may shed more light on this.

2.62 The effects from large acute exposure may conform to the assumptions outlined above but all of these assumptions may not be applicable to the effects of a chronic daily dose of 1 r. Lacking in our knowledge is a formulation of indices of recovery following irradiation at these low levels. The experimental use of the median lethal dose to measure recovery requires pre-irradiation doses of at least 40-50 r to yield definitive data with reasonable numbers of animals.

2.63 Little is known of the nature of the pathological process responsible for life shortening. One theory considers, by analogy to genetic mutations, that the accumulation of radiation injury to the somatic cell chromosomes leads to reproductive death of a somatic cell. This process occurring in a large number of cells may be responsible for the aging of an organism. In the present state of knowledge it is premature to attribute the complex processes of aging to somatic mutations. It seems that extensive studies of the causes of death shown by animal experiments and human surveys may further our knowledge of chronic radiation effects in man.

2.64 In humans the evidence for life span shortening is limited. Mortality studies among U. S. physicians, comparing the effects of occupational exposure of radiologists with other physicians and with the general male population, have not produced definitive answers to the question of whether a decrease in life span occurred in the radiologists. For the general population, estimations of a non-specific life shortening effect from whole body radiation continues to be based on experiments on animals exposed to large doses. There are as yet no data in man to answer the questions of quantitative estimates of life shortening effect per rad of whole body exposure. Equally in question are the existence of a threshold dose, or the dose fractionation effect for exposures commonly experienced by the general population.

Growth and Development

2.65 Only a portion of developmental defects are attributable to genetic origins. It is necessary to distinguish within the totality of congenital defects, those attributable to changes in the genetic material; and of the latter, those which may be due to environmental causes, including radiation. Some geneticists estimate that 10 percent of fertilized ova have some congenital defect (malformation) detectable during that generation. Of this 10 percent, about 0.1 are ascribed to an environmental insult to the developing fetus (such as rubella and other viruses, toxic chemicals, maternal nutritional disturbances, radiation, etc.); about 0.1 are clearly due to simple mendelian genetic systems; and about 0.1 are due to chromosomal aberrations of a particular type. The great bulk of the remaining 0.7 are believed to be due to complex genetic systems whose expression depends on environmental variables operating on alterations of the homeostatic balances of life. Radiation may be one of a myriad of possible causes of congenital defects.

2.66 In animals, effects of radiation on prenatal embryonic development have been demonstrated from 25 r to several hundred r or more, and are closely correlated with the time of gestation at which radiation is given. The prenatal effects include (1) failures of uterine implantation leading to a maternal missed period, or to miscarriages and stillbirths; (2) alterations induced in the varying stages of development of fetal organs which lead to a high neonatal death rate and abnormalities at term; and (3) late stage manifestations, such as subtle changes in physiological states.

2.67 Parts of the human brain and eye are probably susceptible to injury until the last months of gestation. In mice, acute doses of 25-30 r (whole body x-rays) to the fetus produce discernible skeletal defects. It is known from bone studies on human stillbirths that radiostrontium may pass through the placental barrier and become fixed in the skeleton and other organs. It is presumed that exposure of this type may in the early stages of the growing embryo resemble whole body exposure.

2.68 Effects of irradiation on postnatal development are also described. Although it is known that regeneration and repair processes are sensitive to radiation, more quantitative studies under conditions of whole or partial body exposure are needed. In rats, quantitative studies show that growth in body weight is decreased as a result of about 24 r per week whole body irradiation. Localized irradiation of the epiphysis of bones at high doses in humans and animals will cause measurable shortening of the bones. Studies on children exposed to the atomic bomb in Japan indicate that there may be depression of growth rates after irradiation as has been observed in animals. However, little is known in either animals or humans of the after-effects of whole or partial body irradiation in the young in comparison to mature animals, and of the subtle changes induced in their physiological efficiency.

Skin Effects

2.69 Knowledge of effects to the skin of localized exposure to radiation of low penetrating power has accumulated since the discovery of x-rays. The early promulgation of a "tolerance dose" of x-radiation was established by quantitating skin reactions (erythema) with dose. Among early radiologists the chronic radiation produced erythema, dermatitis, and skin cancers. Under modern practices, these conditions should no longer be seen.

Eye Effects

2.70 Injury to the lens serves as a sensitive detecting index of the effect of radiation on the eye. Lens opacities (cataracts) have occurred following exposure of the eye in animals (exposed to neutrons and x-rays), and cyclotron workers, nuclear physicists, and Japanese survivors at Hiroshima and Nagasaki. In man, the minimal single dose producing cataracts is estimated to be approximately 200 rads acute exposure of x- or gamma-rays. In animals the production of cataracts depends on the age and health of the animal, the exposed lens area, and the RBE of the source of radiation. There are no quantitative dose-effect data relating the incidence of cataracts late in life in humans or animals to the acceleration of aging processes.

Summary

1. Acute doses of radiation may produce immediate or delayed effects, or both.

2. As acute whole body doses increase above approximately 25 rems (units of radiation dose), immediately observable effects increase in severity with dose, beginning from barely detectable changes, to biological signs clearly indicating damage, to death at levels of a few hundred rems.

3. Delayed effects produced either by acute irradiation or by chronic irradiation are similar in kind but the ability of the body to repair radiation damage is usually more effective in case of chronic than acute irradiation.

4. The delayed effects from radiation are in general indistinguishable from familiar pathological conditions usually present in the population.

5. Delayed effects include genetic effects (effects transmitted to succeeding generations), increased incidence of tumors, life span shortening, and growth and development changes.

6. The child, the infant, and the unborn infant appear to be more sensitive to radiation than the adult.

7. The various organs of the body differ in their sensitivity to radiation.

8. Although ionizing radiation can induce genetic and somatic effects (effects on the individual during his lifetime other than genetic effects), the evidence at the present time is insufficient to justify precise conclusions on the nature of the dose-effect relationship especially at low doses and dose rates. Moreover, the evidence is insufficient to prove either the hypothesis of a "damage threshold" (a point below which no damage occurs) or the hypothesis of "no threshold" is man at low doses.

9. If one assumes a direct linear relation between biological effect and the amount of dose, it then becomes possible to relate very low dose to an assumed biological effect even though it is not detectable. It is generally agreed that the effect that may actually occur will not exceed the amount predicted by this assumption.

III. SOURCES OF RADIATION EXPOSURE

3.1 For convenience, the exposure of persons to radiation will be divided into three classes: (a) exposures from natural sources; (b) exposures from man-made sources other than environmental sources; and (c) exposures from environmental contamination. Where data are available, the exposures of various critical portions of the body are indicated separately. Of special interest are the gonadal dose because of its genetic significance and the bone marrow dose because of possible leukemogenesis. Therefore, the following discussions center their attention on the genetically significant and bone marrow doses as examples of the general problem.

Natural Sources

3.2 Table 3.1 lists the doses received by persons in the United States from natural sources. The principal exposures from radiation sources outside of the body (external sources) and from sources inside of the body (internal sources) are listed separately.

3.3 The dose from cosmic rays for 38 principal cities in the United States was determined from data on the variation of cosmic ray dose with altitude[1] (Solon et al--1959). As most of the large centers of population are near sea level, the mean dose to the population of the United states from cosmic rays is nearer the lower than the upper limit.

3.4 The dose from terrestrial external gamma rays was estimated by subtracting the cosmic ray component from measurements of the sum of the two components (Solon et al, 1959) and applying an approximate correction (0.6) for the average shielding of the outer tissues of the body. The resulting range of values includes mean values for 38 of the principal cities of the United States. However, it should be noted that doses obtained at different locations within a city varied in several cases by a factor of 2 or 3 for the limited data available. In part, this may be due to shielding of heavy structures or the proximity of structures whose building materials contained small quantities of gamma emitting nuclides.

3.5 When doses from internal sources are added, it appears (Table 3.1) from the limited data available that the radiation dose to soft tissue from all natural sources varies by at least a factor of 2 in the United States.

Man-Made Sources Other Than Environmental Contamination

3.6 Exposure of persons to man-made radiation other than environmental contamination arises principally from (1) exposures received during medical procedures, (2) exposures received by radiation workers during their working hours, (3) exposures to persons in the vicinity of medical and industrial radiation sources (environs), and (4) exposure produced by other sources, such as radium dialed watches, television sets, etc. Table 3.2 summarizes the estimated per capita mean marrow doses and genetically significant doses to the population from man-made sources other than environmental contamination. The per capita dose is the sum of all of the doses received by the population divided by the number of individuals in the population. The annual genetically significant dose to the population is the average of the gonadal doses received by the individuals each weighted for the expected number of children to be conceived subsequent to the exposure.

3.7 For the occupational exposure it is assumed that as much as a half of one per cent of the population might be exposed in the future to as much as an average annual dose of 4 rems. Both estimated figures are high because the fraction of the population occupationally exposed to

[1]Variation of the dose from cosmic rays with latitude is small compared to that with altitude.

radiation and the annual dose they receive at the present time is considerably less than that assumed in Table 3.2. There are presently only about 66,000 radiation workers out of a total employment approximating 120,000 in the Atomic Energy Commission and its contractors (see Table 5.1) and perhaps 250,000 persons occupationally exposed to x-rays in medical applications. Persons in these two areas plus the industrial radiography field probably do not constitute more than 0.2 per cent of the population at the present time. Morgan (1959) indicates that the average annual exposure of radiation workers at Oak Ridge National Laboratory is 0.4 r, and at Hanford, 0.2 r (see Table 5.1). In the fields of medical applications and industrial radiography, the annual doses received by most radiation workers falls within the range of 0.5 to 5 rems. Most of them probably receive doses in the lower half of this range but a few possibly receive more than 5 and some less than 0.5 rems. Thus, the average annual dose for all radiation workers is probably much less than the 4 rems assumed for the calculation at the present time.

3.8 For exposure of persons in the environs it is assumed that one per cent of the population might be involved and they would have an annual dose of as much as 0.5 rems. This assumption concerning per capita dose from the exposure of environs is probably larger than will be obtained in the foreseeable future. The fraction of the population assumed is quite large and it is unlikely that the average individual will receive as much as 0.5 rem per year.

3.9 Unfortunately, there are no data on the mean marrow dose from medical therapy, but it is obvious that diagnostic x-rays contribute considerably to the total exposure from man-made sources other than environmental contamination. While diagnostic x-rays are an important clinical tool, the practitioner of the healing arts should always attempt to balance the risk against the gain for each exposure. He should also assure himself that the most modern techniques are being used in order that the dose is reduced as much as practicable. Current recommendations of the NCRP (H54, 1954 and H60, 1955) indicate methods by which the gonadal dose can be minimized. If these recommendations are observed the bone marrow dose will also be minimized.

Man-Made Environmental Contamination

3.10 Sources of environmental contamination may result from fallout after the explosion of nuclear devices and during the use and processing of fuels for reactors. There are other sources which contribute relatively smaller amounts to environmental contamination.

3.11 Environmental contamination from fallout has received considerable attention over the past decade. When there is a nuclear explosion in the megaton range, the gases cool so slowly that a major portion of the fission products enter the stratosphere where they are distributed widely. Some fission products drift back into the troposphere before losing their radioactivity and are deposited in patterns which depend at least in part upon meteorological conditions. This final fallout, however, takes a long time to drift back to earth so that the fission products from this stratospheric source consist mainly of the long-lived nuclides. For nuclear explosions in the kiloton range, the heat of the fireball is considerably less so that the fission products do not reach the stratosphere but stay in the troposphere. About half of the radioactive material from the troposphere comes back to the earth in about three weeks and most of the fallout reaches the earth in about three months (UNSCEAR p. 99, 1958). From such a fallout, many of the nuclides are of short half-life.

3.12 According to reported estimates,[2] the genetically significant per capita dose in the United States from both external and internal radiation from fallout of cesium-137 will be about 53 millirem in 30 years providing nuclear weapons testing in the atmosphere is not resumed after the cessation at the end of 1958. It was also reported that the per capita mean marrow dose in the United States would be, under the same conditions, about 331 millirem in 70 years from cesium-137 and strontium-90. For continued testing at the same rate as in the previous 5 years, it was estimated that the above numbers should be multiplied by a factor of 8. Other estimates (UNSCEAR 1958 and Feeley 1960) are somewhat lower.

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[2]W. Langham and E. C. Anderson, Fallout from Nuclear Weapons Tests, Hearings of the Joint Committee on Atomic Energy, Congress of the United States, May 1959, p. 1061 ff.

3.13 Under normal operating conditions, most industries in the nuclear engineering field, including the use of reactors, do not now release activity which will give significant contributions to the population dose.

3.14 It is usually considered very unlikely that the core of a reactor would melt down accidentally and release fission products. This possibility, however remote, is considered in designing a reactor. Modern reactors are designed with a containment shell which would permit only a very small portion of the fission products, from a melt-down, to contaminate the environment. However, according to the best engineering estimates, this and other containment provisions will not trap all of the activity. An additional major reduction in the activity released by the shell would substantially increase the cost of the reactor.

3.15 Plants used for the processing of spent fuel elements have a larger potential for contaminating the environment. Here the fuel element is dissolved and the radioactive material is liberated from the fuel element. However, the amount of material treated at any one time is much less than the material present in a reactor. In this process, fission product gases, such as radioactive iodine, bromine, xenon, and krypton are released from the fuel element. Most of the other radionuclides remain in the solutions. Some nuclides, such as cesium-137 and strontium-90, may be separated out for other uses. The remainder of the radionuclides are now stored in huge tanks. Such storage is, of course, expensive.

Summary

3.16 From a limited survey it appears that the human annual gonadal, soft tissue, and bone marrow doses from natural sources may be from 80 to 170 millirem (see Table 3.1).

3.17 The estimated annual genetically significant dose from all man-made sources except environmental contamination probably is about 80 to 280 millirem. The per capita annual mean marrow dose is probably greater than 100 millirem, although no data are available on the contribution from medical radiation therapy. The genetically significant dose and the mean marrow dose are each of the order of the dose received from natural sources. Diagnostic x-rays provide a substantial contribution to these totals (see Table 3.2).

3.18 It has been estimated[3] that fallout will contribute about 53 millirem to the genetically significant per capita dose of the population in 30 years if nuclear weapons testing in the atmosphere is not resumed after the cessation at the end of 1958. If testing were to continue at the same rate as in the previous 5 years, it was estimated that the above number should be multiplied by a factor of 8. The estimated corresponding per capita mean marrow doses for 70 years are 331 millirem and 2648 millirem respectively.

3.19 Under normal operating conditions, most industries in the nuclear engineering field, including the use of nuclear power plants do not now release activity which will give a significant contribution to the population dose.

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[3]W. Langham and E. C. Anderson, Fallout From Nuclear Weapons Tests, Hearings of the Joint Committee on Atomic Energy, Congress of the United States, May 1959, p. 1061 ff.

TABLE 3.1

ANNUAL RADIATION DOSES[1] FROM NATURAL SOURCES

Irradiation	Millirem
By external sources:	
Cosmic rays	32-73
Terrestrial gamma rays	25-75
By internal sources:	
K^{40}	[2]19
C^{14}	[2]1.6
Ra^{226}	[3]?
Total	[4]80-170

[1]Doses to the gonads and other soft tissue including bone marrow.

[2]Report of United National Scientific Commission on the Effects of Atomic Radiation (UNSCEAR, p. 58, 1958).

[3]Unconfirmed research of Muth et al, Brit. J. of Radiol. Suppl. No. 7, 1957, indicates that the dose may be of the order of 2 millirem per year to the gonads and 5 to 15 millirem per year to other soft tissue.

[4]The lungs may receive an additional dose of from 125 to 1570 millirem per year from radon given off by building structures. The spread is caused by variations in ventilation and differences in building materials (UNSCEAR, p. 58, 1958).

TABLE 3.2

ESTIMATED EXPOSURE FROM MAN-MADE SOURCES (OTHER THAN ENVIRONMENTAL CONTAMINATION)[1]

Irradiation	Average annual genetically significant dose to the population	Per capita annual mean marrow dose
	(millirem)	(millirem)
Medical (exposure of patients):		
Diagnostic x-rays	[2] [3]40-240	[4]50-100
Therapy	[5]12	Not available
Internal (radionuclides)	[5]1	10
Occupational	20	20
Environs	5	5
Other (luminous dials, TV, etc.)	[6]2	[6]1-3
Total	80-280	....

[1]Fallout from tests of nuclear weapons is not included (see sub-section on environmental contamination).

[2]International Commission on Radiological Protection (ICRP) and International Commission on Radiological Units and Measurements (ICRU) Joint Study Group Report. Physics in Med. and Biology, 2 107 (1957).

[3]These are probable values.

[4]Report UNSCEAR, p. 66.

[5]Clark, S. H., Bull. of the Atomic Scientists 12 14 (1956). The 12 millirem per year may be an underestimate because patients treated for malignances are not included. Martin (1958), who assumed that these patients might procreate after treatment, obtained a value of 28 for Australia.

[6]Report of UNSCEAR, p. 11.

SECTION IV.—THE DERIVATION OF RADIATION PROTECTION STANDARDS

4.1 Shortly after the discovery of x-rays and natural radioactivity in the late 19th century, it became apparent that exposure to sufficiently large doses could produce both acute manifestations and serious later sequelae in man. Based on relatively limited observations on a rather small number of individuals, attempts were made to define a level at which these obvious deleterious effects would not be seen. With increasing scientific knowledge, based on observations of larger numbers of individuals and laboratory animals and a better understanding of radiation damage, these suggested levels have undergone continuous downward revision. For some time, however, the underlying basic philosophy remained unchanged, and radiation protection standards were based on the premise that there was a dose ("tolerance dose") below which damage would not occur. The validity of this basic assumption was subject to increasing question, first in the field of genetic damage, and later in connection with somatic effects. Thus, by 1954, the National Committee on Radiation Protection and Measurements included the following statement in Handbook 59 (NCRP, H59, 1954):

"The concept of a tolerance dose involves the assumption that if the dose is lower than a certain value—the threshold value—no injury results. Since it seems well established that there is no threshold dose for the production of gene mutations by radiation, it follows that strictly speaking there is no such thing as a tolerance dose when all possible effects of radiation on the individual and future generations are included . . . " and " . . . the concept of a permissible dose envisages the possibility of radiation injury manifestable during the lifetime of the exposed individual or in subsequent generations. However, the probability of the occurrence of such injuries must be so low that the risk would be readily acceptable to the average individual. Permissible dose may then be defined as the dose of ionizing radiation that, in the light of present knowledge, is not expected to cause appreciable bodily injury to a person at any time during his lifetime. As used here, 'appreciable bodily injury' means any bodily injury or effect that the average person would regard as being objectionable and/or competent medical authorities would regard as being deleterious to the health and well-being of the individual . . ."

4.2 With the accumulation of even more quantitative information concerning radiation effects in both animals and humans, and some increased understanding of the mechanisms of radiation injury, the possibility that somatic effects as well as genetic effects might have no threshold appeared acceptable, as a conservative assumption, to increasing numbers of scientists. In discussing its recommendations for additional downward revision of the maximum permissible occupational radiation exposure, the NCRP in 1958 stated (2):

"The changes in the accumulated MPD (maximum permissible dose) are not the result of positive evidence of damage due to the use of earlier permissible dose levels, but rather are based on the desire to bring the MPD into accord with the trends of scientific opinion; it is recognized that there are still many uncertainties in the available data and information . . . ," and, "The risk to the individual is not precisely determinable but, however small, it is believed not to be zero. Even if the injury should prove to be proportional to the amount of radiation the individual receives, to the best of our present knowledge, the new permissible levels are thought not to constitute an unacceptable risk . . . "

4.3 Thus, over the past decade or two, there has been an increasing reluctance on the part of knowledgeable scientists to establish radiation protection standards on the basis of the existence of a threshold for radiation damage and on the premise that this threshold lies not too distant from the point at which impairment is detectable in an exposed individual. Although many scientists are prepared to express individual opinions as to the likelihood that a threshold does or does not exist, we believe that there is insufficient scientific evidence on which to base a definitive conclusion in this regard. Therefore, the establishment of radiation protection guides, particularly for the whole population, should take into account the possibility of damage, even though it may be small, down to the lowest levels of exposure. This involves considerations other than the presence of readily detectable damage in an exposed individual. It also serves as a basis for such fundamental principles of radiation protection as: there should not be any man-made radiation exposure without the expectation of benefit resulting from such exposure; activities resulting in man-made radiation exposure should be authorized for useful applications provided the recommendations set forth in this staff report are followed.

4.4 If the presence of a threshold could be established by adequate scientific evidence, and if the threshold was above the background level and sufficiently high to represent a reasonable working level, a relatively simple approach to the establishment of radiation standards would be available.

4.5 On the assumption that there is no threshold, every use of radiation involves the possibility of some biological risk either to the individual or his descendents. On the other hand, the use of radiation results in numerous benefits to man in medicine, industry, commerce, and research. If those beneficial uses were fully exploited without regard to radiation protection, the resulting biological risk might well be considered too great. Reducing the risk to zero would virtually eliminate any radiation use, and result in the loss of all possible benefits.

4.6 It is therefore necessary to strike some balance between maximum use and zero risk. In establishing radiation protection standards, the balancing of risk and benefit is a decision involving medical, social, economic, political, and other factors. Such a balance cannot be made on the basis of a precise mathematical formula but must be a matter of informed judgment.

4.7 Risk can be evaluated in several different ways before it is balanced against benefit. A logical first step is the identification of known or postulated biological effects. The uncertainty of our present knowledge is such that the biological effects of any given radiation exposure cannot be determined with precision, so it is usually necessary to make estimates with upper and lower limits.

4.8 It is helpful to compare radiation risk to other known hazards in order to maintain perspective or a sense of proportion with respect to the risk. For example, attempts have been made to compare the relative biological risks of various radiation exposure levels to such other industrial hazards as traumatic injuries and to toxic agents employed in industrial processes. Likewise, the possible hazards from various radiation levels have been reviewed in relation to such everyday risks to the general population as the operation of motor vehicles, the possibility of home accidents, and the contamination of our environment with industrial wastes.

4.9 Effects can also be evaluated in terms of the normal incidence of disease conditions usually present in the population which may also be caused by radiation. In a given instance, the portion of the total number of cases of a given disease which might be attributed to radiation may be quite small. Therefore, the significance of a given radiation exposure can appear superficially to be quite different depending upon whether the data are expressed in terms of the absolute numbers of cases of a given condition which will possibly result, or be expressed as percentages of the normal incidence. However, it is extremely difficult to assign any numerical value to the increase which should be permitted in a given abnormal condition. It is also important to remember that at the present time, any numerical predictions of the number or percentage increase in any given condition anticipated as a result of radiation exposure are based on inadequate data and have extremely limited reliability, even though upper and lower limits can be stipulated.

4.10 The biological risk attributable to man-made radiation may also be compared with that from natural sources. This approach is also important in maintaining perspective. Man and lower forms of life have developed in the presence of such natural sources in spite of any radiation damage that may have been present. Perhaps one of the more important advantages to this approach is that it makes due allowance for qualitative as well as quantitative ignorance of yet unrecognized radiation effects, if such exist. Weighing for various somatic as well as genetic effects is also inherently included. It automatically includes a consideration of the largest body of human and subhuman data on radiation effects. One disadvantage is the degree

of conservatism introduced by this approach, since it is likely that only a small fraction of the total incidence of disease results from background radiation.

Summary

4.11 Two factors need to be considered in the formulation of radiation protection standards: biological risk, and the benefits to be derived from radiation use. Maximum benefits cannot be obtained without some risk, and risk cannot be eliminated without foregoing benefits. Therefore some balance must be struck between risk and benefit.

4.12 Since an accurate delineation of risk is impossible, a number of approaches can usefully be employed to aid in the evaluation of risk, and to put risk in reasonable perspective. Each has merit, but such approaches are not mutually exclusive and should be used in combination. An evaluation of benefits in addition to an evaluation of risk is also necessary.

SECTION V.—BASIC GUIDES

5.1 The philosophical bases for derivation of radiation protection standards have been discussed in Section IV, with the conclusion that they are not mutually exclusive, and that consideration should be given to all in the final selection of numerical values. We believe, however, that there are reasons why the relative emphasis placed on the various bases may appropriately be different for the radiation worker and the general population. Additionally, there appear to be a number of reasons why the exposure to the general population should be less than that for occupationally exposed groups. For example:

(1) There is reason to believe that the child and the infant may be particularly sensitive to radiation damage. Children and infants are not included in occupationally exposed groups.

(2) The number of years of exposure to radiation in the course of employment will be less than the average total life span. Therefore, the total accumulated dose will be less for an individual exposed only during a working life than for an individual exposed at the same level from birth through a normal life span to death.

(3) There is considerable evidence that, at least for certain effects, there is a latent period between the time of exposure and the time at which effects are first detectable. The effects of exposure late in life may not become manifest during the normal remaining life span. Whereas, the effects of exposure early in life may well become manifest during the longer remaining life span.

(4) Industrial workers undergo at least some degree of preplacement selection. It is thus possible to exclude from exposure those individuals with intercurrent disease who might be more susceptible to injury.

(5) Insofar as an individual has a choice of occupations, there is, at least in principle, a voluntary acceptance of the small risk potentially involved.

(6) Considerations of population genetics make it desirable to limit gonadal exposure of the whole population.

Radiation Protection Guides for the General Population[1]

5.2 We believe that the current population exposure resulting from background radiation is a most important starting point in the establishment of Radiation Protection Guides for the general population. This exposure has been present throughout the history of mankind, and the human race has demonstrated an ability to survive in spite of any deleterious effects that may result. Radiation exposures received by different individuals as a result of natural background are subject to appreciable variation. Yet, any differences in effects that may result have not been sufficiently great to lead to attempts to control background radiation or to select our environment with background radiation in mind.

5.3 On this basis, and after giving due consideration to the other bases for the establishment of Radiation Protection Guides, it is our basic recommendation that the yearly radiation exposure to the whole body of individuals in the general population (exclusive of natural background and the deliberate exposure of patients by practitioners of the healing arts) should not exceed 0.5 rem. We note the essential agreement between this value and current recommendations of the ICRP and NCRP. It is not reasonable to establish Radiation Protection Guides for the population which take into account all possible combinations of circumstances. Every reasonable effort should be made to keep exposures as far below this level as practicable. Similarly, it is obviously appropriate to exceed this level if a careful study indicates that the probable benefits will outweigh the potential risk. Thus, the degree of control effort does not depend solely on whether or not this Guide is being exceeded. Rather, any exposure of the population may call for some control effort, the magnitude of which increases with the dose.

[1]See Section VII for applicability of these guides.

5.4 Under certain conditions, such as widespread radioactive contamination of the environment, the only data available may be related to average contamination or exposure levels. Under these circumstances, it is necessary to make assumptions concerning the relationship between average and maximum doses. The Federal Radiation Council suggests the use of the arbitrary assumption that the majority of individuals do not vary from the average by a factor greater than three. Thus, we recommend the use of 0.17 rem for yearly whole-body exposure of average population groups. (It is noted that this guide is also in essential agreement with current recommendations of the NCRP and the ICRP.) It is critical that this guide be applied with reason and judgment. Especially, it is noted that the use of the average figure, as a substitute for evidence concerning the dose to individuals, is permissible only when there is a probability of appreciable homogeneity concerning the distribution of the dose within the population included in the average. Particular care should be taken to assure that a disproportionate fraction of the average dose is not received by the most sensitive population elements. Specifically, it would be inappropriate to average the dose between children and adults, especially if it is believed that there are selective factors making the dose to children generally higher than that for adults.

5.5 When the size of the population group under consideration is sufficiently large, consideration must be given to the contribution to the genetically significant population dose. The Federal Radiation Council endorses in principle the recommendations of such groups as the NAS-NRC, the NCRP, and the ICRP concerning population genetic dose, and recommends the use of the Radiation Protection Guide of 5 rem in 30 years (exclusive of natural background and the purposeful exposure of patients by practitioners of the healing arts) for limiting the average genetically significant exposure of the total U. S. population. The use of 0.17 rem per capita per year, as described in paragraph 5.4 as a technique for assuring that the basic Guide for individual whole body dose is not exceeded, is likely in the immediate future to assure that the gonadal exposure Guide is not exceeded. The data in Section III indicates that allocation of this population dose among various sources is not needed now or in the immediate future.

Radiation Protection Guides for Occupational Exposure[2] [3]

5.6 Extrapolation from experience with background radiation to the exposure of the relatively small percentage of the population in the radiation industry is rather unsatisfactory. The difficulties inherent in a careful mathematical balancing of the biological risk against the total gain have been outlined previously. It is possible to estimate the maximum biological damage which could be reasonably expected to result from a given radiation exposure. Using such estimates, a numerical value can be selected at which the radiation risk appears so small as to be justified by even a relatively minor benefit. The NCRP recommends that, for occupational exposure, the radiation dose to the whole body, head and trunk, active blood forming organs, or gonads, accumulated at any age, shall not exceed 5 rems multiplied by the number of years beyond age 18, and that the dose in any 13 consecutive weeks shall not exceed 3 rems. The Federal Radiation Council agrees with the opinion of the NCRP that this dose of ionizing radiation is not expected to cause appreciable body injury to a person at any time during his lifetime. Thus, while the possibility of injury may exist at this dose, the probability of detectable injury is almost certain to be extremely low. Even the use of the more pessimistic assumptions would indicate that the small risk involved is acceptable if the gain is of any significance. Fortunately, this level also appears to be one which is not unduly restrictive in ordinary working circumstances.

5.7 There will be individual circumstances under which compliance with this guide would not be feasible. For example, accidents will occur, but the dose received will usually be de-

[2]See Section VII for applicability of these guides.
[3]In the formulation of Radiation Protection Guides for occupational exposure, special consideration has not been given in this staff report to the possible existence of pregnancy among female workers.

termined by the nature and conditions of the accident and consequently, the dose does not lend itself to prior planning. In addition to accidents, emergency situations will almost certainly arise, but here too, the dose should be determined by the nature of the emergency.

5.8 It is recognized that, even though small, there is a possibility of biological damage to the individual or his progeny from exposures of less than 5 rem per year. For this reason, radiation exposures should always be maintained at the minimum practicable level. Thus, it seems inadvisable to expose man to radiation if no benefit is anticipated.

5.9 It is to be noted that these recommendations are expressed in terms of rem. While the rad is the basic unit in physical dosimetry, some adjustment for the relative damage produced, even in the same individual, by one rad of gamma-rays as compared to one rad of alpha-rays, for example, must be included. (For a definition of terms and a list of RBE conversion factors, refer to Section I.) Because the value for the RBE may change with newer scientific knowledge, and in view of the relative importance of the total accumulated dose throughout a worker's lifetime, agencies and departments may wish to consider the desirability of maintaining exposure records in such a fashion that recalculation of the accumulated dose in rem can be made at any time when changes in the RBE are justified. One technique would be to keep primary exposure records in terms of rads with a stipulation as to the type of radiation involved.

5.10 One can examine the difficulties arising if the average yearly dose of 5 rems for occupational exposure is increased or decreased. Immediately, it is seen from the information in Section II that one cannot increase this level by as much as a factor of 10 without materially increasing the possibility of biological harm, for this is close to the level at which biological damage has been observed (see paragraphs 2.18 and 2.19).

5.11 Fortunately, it appears that there is no necessity for setting the level this high because the doses actually received are generally much less at the present time. It also appears that these recommended levels do not unduly restrict the beneficial use of radiation. In this connection, it is interesting to examine the distribution of doses received by radiation workers. Figure 5.1 shows the dose distribution for all AEC radiation workers. Each of these persons was supposed to receive less than 12 r yearly and not more than 5 r when averaged over a number of years. It appears that about 3 persons per 10,000 were involved in accidents, so they received more than 12 r. Only about 3 per 1,000 received more than 5 r and only about 1 per 100 received more than 3 r. Thus, if there is some assurance that those receiving the high doses in any year are not those who receive them every year, the accumulated dose received by each worker during 50 years of radiation employment will be considerably less than 250 r or 50 x 5r.

5.12 On the other hand, for economic and other operational reasons, one cannot set the level too low. This is not only because of the cost of extra radiation shielding and other radiation protection measures, but even more because of the difficulty of radiation measurements in regions where the radiation levels vary widely in both time and space.

Measurability of External Exposure

5.13 After the selection of Radiation Protection Guides, it is necessary to examine the numbers so selected for their measurability. Measurability here is used in the sense of both sample selection and sample measurement.

5.14 The radiation worker who has a reasonable chance of receiving radiation as a result of his employment can be monitored essentially for the entire time he is on the job. There are instruments available to make measurements with acceptable precision and accuracy at the levels recommended in the Radiation Protection Guides.

5.15 The problem of sampling the human population in the vicinity of an operation which might expose people to radiation may be a very simple one or a very complex one depending on the operation and the distribution of people around the operation. The actual measurement of 0.5 rem per year is usually a difficult one to make. This number is near or below the accuracy level of many widely used monitoring instruments. It will take special methods on the part of the monitoring group to measure this number with sufficient accuracy.

TABLE 5.1

DOSE DISTRIBUTION, AEC RADIATION WORKERS, 1958[1]

Oper. Office	Total employees monitored EXTERNAL	Number of annual accumulated exposures in ranges reported: 0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15+
1........	3,411	3,359	47	5													
2........	3,288	2,785	260	143	47	24	11	9	4	4	1						
3........	11,377	10,825	383	97	32	16	9	6	0	1							8
4........	8,089	7,672	373	44													
5........	15,018	12,152	1,845	697	198	78	26	5	4	2	1	1	1	3	2	0	3
6........	1,647	1,533	61	26	9	3	3	0	3	1	3						
7........	3,332	2,867	198	117	67	37	9	4	9	15	6	3					
8........	10,758	9,774	573	405	6												
9........	3,670	3,479	96	49	21	11	6	5	3								
10........	1,394	1,279	82	25	5	1	1										1 (15 rem ± 40 percent)
11........	3,838	3,645	118	44	22	1	1	2	4								
12........	85	80	5														
Totals....	65,907	59,455	4,041	1,652	407	171	67	31	27	23	11	4	1	3	2	0	12

[1]Data supplied by the Atomic Energy Commission.

Organ Doses

5.16 The recommendations of this staff report include (paragraph 7.10) recommendations for organ doses to the radiation worker which are believed to carry a biological risk not greater than that represented by 5 rem of whole body exposure. These organ doses may also represent a starting point for the derivation of Radioactivity Concentration Guides for the worker.

5.17 The establishment of individual organ doses for the general population involves additional considerations which preclude the possibility of relating them to the Guides for the radiation worker by a simple mathematical relationship that is applicable to all situations. An extension of the recommendations contained in this document in order to provide guidance in the derivation of Radioactivity Concentration Guides for the population is recognized as an important responsibility of the Federal Radiation Council. The complexities are such that a detailed study is required. In order to make our basic recommendations known as soon as possible, it was deemed advisable not to delay the release of our initial recommendations pending the completion of our studies of this and certain other important problems. It appears that there will be no undue risk nor undue hardship if the Federal agencies and departments continue their present practices concerning organ doses for the general population during this interim period.[4]

Summary

5.18 It appears feasible to establish a Radiation Protection Guide for the general population with primary relationship to background radiation levels. For radiation workers a Guide can be established which appears to be generally practicable in its application, and for which even pessimistic predictions of biological damage would be so small as to warrant acceptance if any appreciable benefit results.

5.19 It is not reasonable to establish Radiation Protection Guides which take into account all possible combinations of circumstances. Every reasonable effort should be made to keep exposures below any level selected. Similarly, it is obviously appropriate to exceed the level if careful study indicates that the probable benefits will outweigh the potential risk. Thus, the degree of control effort does not depend solely on whether or not this Guide is being exceeded. Rather, any exposure may call for some control effort, the magnitude of which increases with the dose.

5.20 There are many pertinent reasons why the Radiation Protection Guide for the general population should be lower than that for the radiation worker. Although it is feasible to monitor essentially all exposure to radiation workers, a similar approach to exposure of the general population is not generally feasible. As an operational technique, where the individual whole body doses are not known, a suitable sample of the exposed population should be developed whose protection guide for annual whole body dose will be 0.17 rem per capita per year. It is emphasized that this is an operational technique which should be modified to meet special situations.

5.21 The complexities of establishing guides applicable to radiation exposure of all body organs for the population preclude their inclusion in the staff report at this time. However, current concentration guides now used by the Federal agencies appear appropriate on an interim basis.

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[4]For one approach to this problem, see Recommendations of the International Commission on Radiological Protection, (Sept. 9, 1958), page 16, paragraph 68.

SECTION VI.—DERIVED GUIDES

6.1 This section is concerned with the amount of radioactive material, deposited internally in the body or its organs ("body burdens" and "organ burdens"), which results in a certain physical radiation dose; the amount of environmental contamination with radioactive material which produces a given body or organ burden (Radioactivity Concentration Guides); and accompanying levels in the body excreta.

Body and Organ Burdens

6.2 Calculation of the physical dose delivered to a given mass of material as the result of homogeneous distribution of a known quantity of radioactive material throughout a volume is rather straight-forward, and can be made with considerable precision and accuracy. This statement is especially valid if the volume involved is in some standard geometric arrangement, such as a sphere. Similar calculations regarding the physical dose to all or a part of the human body as a result of radioactive material deposited within it will yield data which diverge from the true value for several reasons, including the following:

(1) Distribution of the radioactive material may be nonhomogeneous because of selective distribution between organs or between portions of the same organ. For example, the thyroid gland has a high degree of selective uptake for radioactive iodine as compared to the body as a whole; various major portions of the same bone may contain differing amounts of radium, dependent, at least in part, upon relative growth rates.

(2) At the microscopic level there may be a significant degree of nonhomogeneity of deposition. For example, not only will the radium content of various major portions of the bone differ, but within a single major portion different cells or groups of cells may contain widely differing quantities of radionuclides. Likewise, colloidal thorium oxide in the liver may concentrate almost entirely in certain types of cells, leaving other cell types essentially free of contamination.

(3) The shape of the organ or whole body may differ from any simple geometric form. Few organs of the body are truly spherical, and the majority of body organs are not true simple geometric shapes, such as cylinders, cubes, and ellipsoids.

6.3 With highly penetrating radiation, such as energetic gamma rays, the lack of homogeneous distribution may introduce only a relatively small error. However, with radiations of very low penetrating power such as alpha emissions, nonhomogeneity can result in variations by several orders of magnitude (factors of ten) among different cells in the same organ. With regard to the shape of body organs or the whole body, calculations are most often made on the basis of an idealized geometry; this simplification does not introduce serious errors into the calculations. For example, the variations introduced by considering a body organ as a sphere or a cylinder do not introduce errors which are significant compared to the lack of quantitative knowledge concerning biological effects of irradiation.

6.4 Thus, for highly penetrating radiation the relatively straight-forward and comparatively simple calculation relating body or organ burden to physical dose provides relatively accurate answers. For less penetrating radiations such as beta rays, the distribution pattern becomes more important, but, giving due regard to this problem, the calculations should ordinarily not err by orders of magnitude. With even less penetrating radiation such as alpha particles, however, the potential errors in the calculations are such as to make the answers clearly suspect.

6.5 As an additional complication, assessment of the biological significance of internally deposited radioactive materials emitting particles with high linear energy transfer, such as alphas, require the introduction of a factor for relative biological effectiveness. Thus, the computation of the body burden of beta or gamma emitting material which is biologically equivalent to a given amount of alpha emitting material is fraught with many pitfalls and inaccuracies.

Radioactivity Concentration Guides

6.6 The measurement of body burdens provides information regarding the extent to which an individual has accumulated radioactive materials. However, it is not always practical to monitor the body burdens resulting from environmental contamination solely by the use of direct measurements on the human body, its tissues, or excreta. Although certain supplemental information can be obtained by monitoring the organ and body burdens of animals, this approach also has significant practical limitations. Furthermore, it is usually desirable to predict the significance of environmental contamination without waiting until it has accumulated in humans or animals.

6.7 For these reasons, direct data on the levels of environmental contamination are being collected, and it is necessary to have guides or benchmarks against which these environmental contamination levels can be evaluated. The National Committee on Radiation Protection and Measurements and its international counterpart have been publishing, for many years, tables of "maximum permissible concentrations" of radionuclides in air and in water for radiation workers.

6.8 Our understanding of the basis used in the derivation of these values is:

For the majority of radionuclides, the body burden which would result in a specified average annual dose is calculated. The doses used for this purpose are 15 rems for most individual organs of the body, 30 rems when the critical organ is the thyroid or the skin, and 5 rems when the gonads or the whole body is the critical organ. For bone seekers, the estimation is based on the deposition of radioactive material, the relative biological effectiveness, and a comparison of the effective energy release in the bone with the effective energy release from a body burden of 0.1 microgram of radium-226 plus daughters. According to certain calculations, this bone limit may correspond to approximately 30 rems per year. However, the difficulties inherent in estimating the physical dose to organs from alpha emitting isotopes, together with the relatively large amount of direct information on the biological effects of various body burdens of radium, have led the NCRP to use this basis for its recommendations. Once the "permissible body burden" has been decided upon, calculations are made as to the daily intake which, continued over a 50-year period, would not result in an accumulation greater than the permissible body or organ burden. (COMMENT: It is to be noted that the limiting factor is a maximum annual dose rate by the end of the period of exposure. Within this limitation there can be differences in the total accumulated dose depending upon the time taken for the isotope to reach an equilibrium concentration in the body. For example, with the same maximum dose rate, the total accumulated dose with a short half-life bone-seeker could be approximately twice the accumulated dose from a long half-life bone-seeker.) While biological data are introduced where available, the basis of much of these calculations is the so-called "standard man" which provides representative constants for the many variables involved. With regard to the determination of permissible intake by ingestion, among the variables involved are:

(1) The fraction of the ingested material which is absorbed into the blood from the gastro-intestinal tract. (COMMENT: Even for a given radionuclide, this may be quite variable depending upon the individual, the chemical form in which the radionuclide is present and its relative solubility, and the influence of other materials also present in the gastro-intestinal tract.)

(2) The fraction of material present in the blood which becomes deposited in the critical organ. (COMMENT: Here again, there will be appreciable individual variations and, of course, major differences with various isotopes.)

(3) Rate of uptake and the time of retention of the material in the critical organ.

6.9 Available biological data were utilized in the NCRP-ICRP computations whenever available. In many cases, the available data are extremely meager, and for certain isotopes, essentially nonexistent. Thus, there is a rather high degree of uncertainty in the calculation of permissible daily intakes, especially for the less adequately studied radionuclides. Even ignoring individual variability, estimates of permissible intakes of ingested radionuclides might vary by factors of 10 to 100 if all of the errors worked in one direction. This, however, is a rather unlikely situation and it appears from the rather meager direct data that, for ingestion, the estimates may be correct within a factor of less than 10.

6.10 Similar considerations are also involved for inhaled radioactive material, except that an estimate of the fraction of inhaled material which reaches the lungs and becomes absorbed into the blood stream is used, instead of the fraction absorbed from the gastro-intestinal tract for ingested material. Estimates and calculations of permissible intakes for inhalation appear much less reliable than for those for ingestion. This results primarily from our rather poor understanding of absorption from the lungs and such added complexities as the effect of particle size. The possible errors with regard to inhaled radionuclides being greater than for ingested radionuclides, it is possible that these intake values could be incorrect by even several orders of magnitude, especially if allowance is made for the existence of variations between individuals.

6.11 Once the NCRP has determined "permissible daily intake" by ingestion or inhalation, "maximum permissible concentrations" in air and water are derived by assuming that the total daily intake of water is 2.2 liters and that the water is uniformly contaminated; and that the total breathing rate is 2×10^7 milliliters per 24 hours and the air is likewise uniformly contaminated. These give values for the "168-hour week" which are then adjusted upward by a factor of 3 for ingestion and a factor of 3 for inhalation to allow for the shorter time exposure involved in a 40-hour week.

6.12 When lower Radiation Protection Guides are selected for the whole population as compared to the worker, this includes allowances for differential sensitivity between children and adults. However, in establishing Radioactivity Concentration Guides, consideration must also be given to the possibly different ratios of intake to uptake for adults and children. Whether this additional difference is sufficiently great to alter the final recommendation cannot be decided without thorough consideration of the specific radionuclide at hand.

6.13 It is also important to note that guides for continuous exposure are not readily converted to guides for short-term exposure by any simple mathematical relationship appropriate to all radionuclides. It is essential that detailed study of this problem be conducted as expeditiously and thoroughly as possible.

6.14 Taking the above factors into account, attention is being given to the establishment of numerical values for Radiation Concentration Guides applicable to the general population for the radionuclides of immediate practical importance to whole population exposure.

Determination of Body Burdens in the Intact Human

6.15 Because of the many complications inherent in attempts to establish Radioactive Contamination Guides for the environment, attempts to determine body burden in the intact human have been made both as a control measure and as a technique for refinement of our knowledge regarding the relationship of intake to body or organ burdens. Historically, the quantitative determination of the radon content of the exhaled air has been used for decades as a technique for estimating the body burden of radium, the radioactive parent of radon. This particular technique has proved to be an extremely valuable one and the relationship has been substantiated by direct determination of the radium content of the skeleton of a few individuals. There are, however, relatively few radioactive materials which are deposited in body organs in a solid form and which decay to radioactive gaseous daughter products.

6.16 An additional approach has been to determine the radioactive content of the urine and feces in order to provide data to estimate the body or organ burden. This approach eliminates many of the uncertainties involved in converting intake to uptake. It does not, however, provide a direct answer as the excretion rate of any given radioactive material will vary between individuals and within the same individual from time to time. An important limitation in this technique arises from the fact that the excreta will contain not only a portion of the radioactive material which truly represents the organ burden, but also additional amounts may be present as a result of excretion of radioactivity which is not fixed in the tissues. Thus, measurements of excreta are particularly unreliable at relatively short times after an exposure, or during a continuing exposure. Additionally, the amounts in the excreta will usually be only a very small fraction of the body burden, and thus the quantities involved at levels of interest may be so small as to require extremely sophisticated radiochemical analytical techniques. In spite of these limitations, the relative directness of this approach as compared to the estimation of human exposure by analysis of environmental samples has led to its practical application in certain installations. It is to be noted, however, that the difficulties in the conduct of the procedures and interpretation of the data suggest that this method is not likely to be immediately useful for the study of problems related to exposure of large population groups.

6.17 One other approach to the determination of body or organ burdens is the use of "whole-body counters." This method can provide extremely useful information, but has several important limitations:

(1) The emissions of the radionuclide under consideration must have sufficient penetrating power to pass through intervening body tissues.

(2) The quantities involved must be sufficiently great to yield significant data in a reasonable period of time.

(3) For detection of very low levels, the equipment needed and the capabilities required for its operation can result in practical limitations when attempts are made to apply this technique to large numbers of people.

Suitability and Measurability

6.18 At the present time the serious gaps in knowledge which exist with regard to factors involved in the establishment of derived standards make them unsuitable as exact standards. Occasional short-term excesses should not be cause for undue concern. Meanwhile, major effort should be expended to determine the various unknowns, particularly those which relate intake to uptake in the body, with greater accuracy.

6.19 It appears that techniques are available to detect and measure, with adequate accuracy, environmental contamination near the levels currently recommended by the NCRP at least for several of the more important radionuclides. Such measurements are not necessarily simple or inexpensive, but should be within the competence of routine laboratories. However, the procedures involved may be sufficiently complicated that sampling on only a representative portion of the environment is indicated.

Atmospheric Contamination in Uranium Mines

6.20 In addition to the current recommendations of the NCRP, the American Standards Association (ASA) has been active in the establishment of recommendations in this field concerning air contamination from radon and its daughter products. It appears that quite different approaches are used by these two groups, and the apparent differences are not readily explainable on a simple basis. Rather, there are differences as to whether primary emphasis is placed on dose calculations or on direct biological evidence and operational considerations. These recommendations are expressed in terms of different radionuclides, so that direct numerical comparison is not easily done. It is not immediately apparent that the measurements actually taken in the mines are directly applicable to the NCRP standard. It does appear prudent to assume, however, that significant numbers of individuals are being exposed to radiation in the mines that are in excess of the recommendations of either group. It is desirable, therefore, to make every reasonable attempt, on a continuing basis, to keep the exposures as low as practical. Reduction of the contamination to the recommended levels would be difficult and even unfeasible in some cases.

6.21 In the meantime, the exposed group is being kept under close medical surveillance. This program should be continued, and expanded if there appears to be any probability of securing additional significant information. In addition, major efforts should be made to better define the radionuclide of principal significance to this problem.

Summary

6.22 Reasonably accurate estimates can usually be made of the amount of internally deposited radioactive material equivalent to any given dose to a critical organ of the body. However, the establishment of guides as to the amount of material which, when taken into the body, will yield such organ burdens is fraught with many uncertainties. Further extension of the estimation to indicate the equivalent amount of environmental contamination is even more uncertain. The potential errors are greater with inhaled contamination than with ingested materials. Extension to individual portions of the environment further compounds the possible errors. The possibility of multiple radionuclides in the same critical organ must be considered, and appropriate allowances made to be certain that the total dose to that organ is not excessive. At the present time, it therefore does not seem appropriate to consider Radioactive Concentration Guides or other derived standards as anything more than guidance levels, to be applied with judgment and discretion.

6.23 It is critical to note that no single standard is applicable to all situations. For example, the level at which the release of radioactivity from normal operations of a nuclear energy plant should be restricted might be quite different from the levels at which a food or milk supply is destroyed or discarded.

SECTION VII.—SUMMARY AND RECOMMENDATIONS

7.1 To provide a Federal policy on human radiation exposure, the Federal Radiation Council was formed in 1959 (Public Law 86-373) to ". . . advise the President with respect to radiation matters, directly or indirectly affecting health, including guidance for all Federal agencies in the formulation of radiation standards and in the establishment and execution of programs of cooperation with States . . . ." The present staff report is a first step in carrying out this responsibility.

7.2 The scope of this staff report is limited to provide some basic radiation protection recommendations which are required. Some of these recommendations should be considered only of an interim nature. Periodic review will be necessary to incorporate new information as it develops. Only peacetime uses of radiation which affect the exposure of the civilian population are considered at this time. A further limitation of the staff report is that it does not consider the effects on the population arising from major nuclear accidents. Certain of the classes of radiation sources are now regulated by various Federal agencies. However, there are some which are not so regulated but which should be considered when dealing with the overall exposure of the population to radiation. Therefore, this staff report considers exposure of the population from all sources except those excluded above.

7.3 Only that portion of the knowledge of the biological effects of radiation that is significant for setting radiation protection standards is considered. Published information is summarized in this report; details may be obtained from reading the original documents. Among the items of most immediate interest to the establishment of radiation protection standards are the following:

1. Acute doses of radiation may produce immediate or delayed effects, or both.
2. As acute whole body doses increase above approximately 25 rems (units of radiation dose), immediately observable effects increase in severity with dose, beginning from barely detectable changes, to biological signs clearly indicating damage, to death, at levels of a few hundred rems.
3. Delayed effects produced either by acute irradiation or by chronic irradiation are similar in kind, but the ability of the body to repair radiation damage is usually more effective in the case of chronic than acute irradiation.
4. The delayed effects from radiation are in general indistinguishable from familiar pathological conditions usually present in the population.
5. Delayed effects include genetic effects (effects transmitted to succeeding generations), increased incidence of tumors, life span shortening, and growth and development changes.
6. The child, the infant, and the unborn infant appear to be more sensitive to radiation than the adult.
7. The various organs of the body differ in their sensitivity to radiation.
8. Although ionizing radiation can induce genetic and somatic effects (effects on the individual during his lifetime other than genetic effects), the evidence at the present time is insufficient to justify precise conclusions on the nature of the dose-effect relationship especially at low doses and dose rates. Moreover, the evidence is insufficient to prove either the hypothesis of a "damage threshold" (a point below which no damage occurs) or the hypothesis of "no threshold" in man at low doses.
9. If one assumes a direct linear relation between biological effect and the amount of dose, it then becomes possible to relate very low dose to an assumed biological effect even though it is not detectable. It is generally agreed that the effect that may actually occur will not exceed the amount predicted by this assumption.

7.4 To clarify the most critical problem areas concerning quantitative relationships of the effects of irradiation on man, it is recommended that special attention be given to the following research efforts:

1. Increasing epidemiological studies on humans who have been exposed to radiation especially in doses sufficient to offer some probability that deleterious effects can be found.
2. Continuing studies on the mechanism of radiation damage and of the interaction of radiation with matter at the cellular level and at the molecular level.
3. Studies designed to determine more adequately the relationship between damage and dose at low total dose and low dose rates. Included should be more precise information at higher levels from which the relationships at lower levels may be inferred.

7.5 The various current sources of radiation exposure to the U. S. population are discussed in Section III. It should be noted that the radiation exposure to patients by practitioners of the healing arts is in the same order as natural background, when averaged over the population. The average exposure to the U. S. population from activities of the nuclear energy industry, under current practices, is less than that from background by a substantial factor.

7.6 If the presence of a threshold for radiation damage could be established by adequate scientific evidence, and if this threshold were above the background level and sufficiently high to represent a reasonable working level, it would serve as a relatively simple basis for the establishment of radiation protection standards. However, with the accumulation of quantitative information concerning radiation effects in both animals and humans, and some increased understanding of the mechanisms of radiation injury, the possibility that somatic effects as well as genetic effects might have no threshold appeared acceptable, as a conservative assumption, to increasing numbers of scientists. On the basis of this conservative assumption, radiation protection standards must be established by a process of balancing biological risk and the benefits derived from radiation use. Such a balance cannot be made on the basis of a precise mathematical formula but must be a matter of informed judgment. Several approaches towards the evaluation of the risk are discussed in Section IV. These approaches, together with the evaluation of benefits and useful applications by the agencies, have been used in the formulation of the recommendations in this staff report.

7.7 Under the working assumptions used, there can be no single "permissible" or "acceptable" level of exposure, without regard to the reasons for permitting the exposure. The radiation dose to the population which is appropriate to the benefits derived will vary widely depending upon the importance of the reason for exposing the population to a radiation dose. For example, once weapons testing in the atmosphere has taken place, the dose to be permitted in lieu of such alternatives as depriving the population of essential foodstuffs might also be quite different from levels used in the planning phases. As another example, for radiation workers, emergency situations will almost certainly arise which make exposures in excess of those applicable to normal operations desirable.

7.8 Also, under the assumptions used, it is noted that all exposures should be kept as far below any arbitrarily selected levels as practicable. There should not be any man-made radiation exposure without the expectation of benefit resulting from such exposure. Activities resulting in man-made radiation exposure should be authorized for useful applications provided the recommendations set forth in this staff report are followed. Within this context, any numerical recommendations should be considered as guides, and the need is for a series of levels, each of which might be appropriate to a particular action under certain circumstances.

7.9 The term "maximum permissible dose" is used by the NCRP and ICRP for the radiation worker. However, this term in often misunderstood. The words "maximum" and "permissible" both have unfortunate connotations not intended by either the NCRP or the ICRP. This report introduces the use of the term Radiation Protection Guide (RPG). This term is defined as, the radiation dose which should not be exceeded without careful consideration of the reasons for doing so; every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable.

7.10 There can, of course, be quite different numerical values for the Radiation Protection Guide, depending upon the circumstances. It seems useful, however, to recommend Guides which appear appropriate for normal peacetime operations. It is recognized that our present knowledge does not provide a firm basis within a factor of two or three for the selection of any particular numerical value in preference to another value. Nevertheless, on the basis set forth in Section V, the following Radiation Protection Guides are recommended for normal peacetime operations:

Type of exposure	Condition	Dose[1] (rem)
Radiation worker:		
(a) Whole body, head and trunk, active blood forming organs, gonads, or lens of eye.	Accumulated dose	5 times number of years beyond age 18
	13 weeks	3
(b) Skin of whole body and thyroid	Year	30
	13 weeks	10
(c) Hands and forearms, feet and ankles.	Year	75
	13 weeks	25
(d) Bone	Body burden	0.1 microgram of radium-226 or its biological equivalent
(e) Other organs..................	Year	15
	13 weeks	5
Population[2]		
(a) Individual[3].....................	Year	0.5 (whole body)
(b) Average[3]........................	30 years	5 (gonads)

[1]Minor variations here from certain other recommendations are not considered significant in light of present uncertainties.
[2]See Section V for reasons why these values differ from those applicable to radiation workers.
[3]See Paragraph 5.4 for applicability of these levels.

7.11 Recommendations are not made concerning the Radiation Protection Guides for individual organ doses to the population, other than the gonads. Unfortunately, the complexities of establishing guides applicable to radiation exposure of all body organs preclude their inclusion in the report at this time. However, current protection guides used by the agencies appear appropriate on an interim basis.

7.12 These guides are not intended to apply to radiation exposure resulting from natural background or the purposeful exposure of patients by practitioners of the healing arts.

7.13 The Federal agencies should apply these Radiation Protection Guides with judgment and discretion, to assure that reasonable probability is achieved in the attainment of the desired goal of protecting man from the undesirable effects of radiation. The Guides may be exceeded only after the Federal agency having jurisdiction over the matter has carefully considered the reason for doing so in light of the recommendations in this staff report.

7.14 This staff report also introduces the term Radioactivity Concentration Guide (RCG) defined as: the concentration of radioactivity in the environment which is determined to result in organ doses equal to the Radiation Protection Guide. Within this definition, Radioactivity Concentration Guide can be established only after the Radiation Protection Guide is decided upon. Any given Radioactivity Concentration Guide is applicable only for the circumstances under which use of its corresponding Radiation Protection Guide is appropriate.

7.15 As discussed in Section VI, reasonably accurate estimates can be made of the amount of internally deposited radioactive material resulting in any particular organ dose. However, the establishment of guides as to the amount of material which, when taken into the body, will yield such organ doses is fraught with many uncertainties. Further extension of the estimation to indicate the equivalent amount of environmental contamination is even more uncertain. The potential errors are even greater with inhaled contamination than with ingested materials. Extension to individual portions of the environment further compounds the possible errors.

7.16 This staff report, therefore, does not contain specific numerical recommendations for Radioactivity Concentration Guides. However, concentration guides now used by the agencies appear appropriate on an interim basis. Where appropriate radioactivity concentration guides are not available, and where Radiation Protection Guides for specific organs are provided in this staff report, the latter Guides can be used by the Federal agencies as a starting point for the derivation of radioactivity concentration guides applicable to their particular problems. The Federal Radiation Council has also initiated action directed towards the development of additional Guides for radiation protection.

7.17 Particular attention is directed to the possibly different ratios of intake to uptake for adults and children. There is no simple numerical relationship between Radioactivity Concentration Guides for the worker and for the general population, even if such a simple relationship is adopted for Radiation Protection Guides.

7.18 With particular relationship to the establishment of Radioactivity Concentration Guides, the following research needs (in addition to those listed in paragraph 7.4) are pointed out:

1. Efforts to design design better and less expensive radiation monitoring instruments and methods.
2. Extensive studies to determine the relationship between concentration of radioactivity in food, air and water, and the ultimate disposition of these by the body.
3. Studies designed to elucidate the relationship between the intake of radionuclides in various chemical forms and their subsequent uptake. Presently, many compounds of a given radionuclide are treated as though they were the same compound.
4. Studies to elucidate the difference between children and adults in their uptake and disposition of radioactivity and their radiation sensitivity.

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background material for the development of radiation protection standards

September 1961

Staff Report of the

FEDERAL RADIATION COUNCIL

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SECTION I.—INTRODUCTION

Scope

1.1 Report No. 1 of the Federal Radiation Council provided a general philosphy or radiation protection for Federal agencies. It introduced and defined the term "Radiation Protection Guide (RPG)." It provided numerical values for Radiation Protection Guides for the whole body and certain organs of radiation workers and for the whole body of individuals in the general population, as well as an average population gonadal dose. It introduced as an operational technique where individual whole body doses are not known, the use of a "suitable sample" of the exposed population in which the guide for the average exposure of the sample should be one-third the RPG for individual members of the group. It emphasized that this operational technique should be modified to meet special situations. In selecting a suitable sample, particular care should be taken to assure that a disproportionate fraction of the average dose is not received by the most sensitive population elements. The observations, assumptions, and comments set out in the memorandum published in the Federal Register on May 18, 1960, are equally applicable to this report.

1.2 This report is concerned with the problem of providing guidance for Federal agencies in activities designed to limit exposure of members of population groups to radiation from radioactive materials deposited in the body as a result of their occurrence in the environment. Included are the following: (1) Radiation Protection Guides for certain organs of individuals in the general population, as well as averages over suitable samples of exposed groups, (2) guidance on general principles of control applicable to all radionuclides occurring in the environment, (3) some general principles by which Federal agencies may establish appropriate concentration values, and (4) specific guidance in connection with exposure of population groups to radium-226, iodine-131, strontium-90, and strontium-89.

1.3 In Report No. 1, the RPG's for radiation workers apply to individuals. Similarly, the whole body RPG for the general population of 0.5 rem per year applies to individual members of the general population. As this report is concerned with radioactive materials in the environment, individual whole body or organ doses will usually not be known. Therefore, this report provides Radiation Protection Guides not only for individuals in the general population, but also, using the operational technique referred to in paragraph 1.1, for the average of suitable samples of exposed population groups. In the development of the guidance on intake, the Radiation Protection Guides for averages have been used.

1.4 For radionuclides not considered in this report, Federal agencies should use concentration values in air, water, or items of food which are consistent with recommended Radiation Protection Guides and the general guidance on intake.

1.5 In the future, the Council will direct attention to the development of appropriate radiation protection guidance for those radionuclides for which such consideration appears appropriate or necessary. In particular, the Council will study any radionuclides for which useful applications of radiation or nuclear energy require release to the environment of significant amounts of these nuclides. Federal agencies are urged to inform the Council of such situations.

1.6 Radiation Protection Guide has been defined in FRC Report No. 1 (see paragraph 1.18). For convenience, it is repeated here.

> "Radiation Protection Guide (RPG) is the radiation dose which should not be exceeded without careful consideration of the reasons for doing so; every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable."

1.7 Report No. 1 also introduced and defined the term "Radioactivity Concentration Guide." This term is not used in this report. The guidance in this report is concerned with total daily intake from all sources of radionuclides rather than concentration values in air, water, or individual items of food. Agencies, however, may find the term "Radioactivity Concentration Guide" useful in some of their programs.

Preparation of the Staff Report

1.8 The preparation of this report followed a pattern similar to that for Report No. 1. The Federal Radiation Council has received written comments from, and consulted with: (1) members of various Federal agencies responsible for the administration of radiation protection programs, (2) governmental and non-governmental scientists in many related disciplines, and (3) other individuals and groups who are interested in the subject.

1.9 In developing the recommendations given in this report, the staff of the Council considered the extensive studies made by the National Committee on Radiation Protection and Measurements (NCRP) and the International Commission on Radiological Protection (ICRP) of the behavior and effects of the radionuclides under discussion. The Council staff consulted scientists from the many disciplines involved in the studies such as physicians, radiobiologists, health physicists, radiochemists, and physicists. Many of the scientists consulted were, or had been, affiliated with NCRP, ICRP, the National Academy of Sciences (NAS), the American Standards Association (ASA), and other scientific groups. The staff also studied available literature and publications of the above groups as well as those of the Medical Research Council and the Agricultural Research Council of the United Kingdom and the United Nations Scientific Committee on the Effects of Atomic Radiation. In some consultations the Council staff had the opportunity to review current unpublished biological data.

1.10 In order to consider as completely as possible the many factors involved in establishing radiation protection standards for the general population, the Council solicited comments from interested organizations and individuals. For this purpose, the Council prepared and transmitted widely a paper stating major policy issues involved in the development of radiation protection guidance in connection with the radionuclides considered in this report. Among these policy issues is the question as to the appropriateness of specific radiation protection standards from the point of view of their social and economic impact. Questions of this sort do not lend themselves to exact quantitative treatment. They are matters of judgment on which the best available information is brought to bear.

Radiation Protection Guides

1.11 It has been emphasized in Report No. 1 of the Federal Radiation Council that the establishment of radiation protection standards involves a balancing of the benefits to be derived from the controlled use of radiation and atomic energy against the risk of radiation exposure. This principle is based upon the position adopted by the Federal Radiation Council that any radiation exposure of the population involves some risk; the magnitude of which increases with the exposure. As stated in "Radiation Protection Guidance for Federal Agencies," approved by the President, May 13, 1960, "There should not be any man-made radiation exposure without the expectation of benefit resulting from such exposure." In recommending use of the term, "Radiation Protection Guide" it was stated that "This term is defined as the radiation dose which should not be exceeded without careful consideration of the reasons for doing so; every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable." Consistent with these principles, no exposure to radiation should be permitted unless it satisfies two criteria:

(1) The various benefits to be expected as a result of the exposure, as evaluated by the appropriate responsible group, must outweigh the potential hazard or risk, and

(2) the reasons for accepting or permitting a particular level of exposure rather than reducing the exposure to a lower level must outweigh the decrease in risk to be expected from reducing the exposure.

1.12 In view of the considerations discussed above, ideally, an individual radiation protection guide should be developed for each activity or set of circumstances involving exposure to radiation. Recognizing the impracticability of establishing an individual guide for each application, the Council, in its Report No. 1, pointed out the need for a compromise between this ideal and

the application of a single guide to widely differing sets of conditions. The following is taken from the Council's recommendations approved by the President:

> "There can be no single permissible or acceptable level of exposure without regard to the reasons for permitting the exposure . . . It is basic that exposure to radiation should result from a real determination of its necessity.
>
> There can be different Radiation Protection Guides with different numerical values, depending upon the circumstances. The guides recommended herein are appropriate for normal peacetime operations."

1.13 On the basis of extensive consultation, the Council has recommended to the President a set of Radiation Protection Guides which represent a generalized balance between the considerations discussed above. Despite wide differences in the assignment of relative values to the various factors involved, the Council believes that the overall benefits from useful activities involving exposures to radiation at levels within those specified in these guides will outweigh the risks associated with such exposures. There is also sufficient experience in limiting radiation exposures to levels similar to these to demonstrate the general feasibility, with few exceptions, of operating at or below the levels specified in these guides in normal peacetime operations.

1.14 The Federal agencies, when applying these Radiation Protection Guides should recognize that they represent generalized and not specific guidance. Because the reasons for accepting or permitting exposure to radiation vary so widely from one situation to another, the guides cannot represent the most appropriate ones for some situations without being inappropriately high or low for others. Each agency should determine, in any specific application, the extent to which the generalized guides apply in the specific situation. For example, certain applications may be able to be conducted at a guide specifying a lower dose than the RPG recommended by the Council. On the other hand, some applications which are not practicable under existing guides and for which the needs are very great may require a guide specifying a higher dose. The possibility of certain situations, such as accidents, may require the development of guides to be used when an agency considers such drastic actions as exclusion of persons from a specified area, evacuation, or condemnation of supplies of food.

1.15 "Radiation Protection Guidance for Federal Agencies" published in the Federal Register May 18, 1960, recognized that in certain instances the balance of benefit versus risk might necessitate an RPG higher than specified for normal peacetime operations. This was expressed in the following language:

> "The guides may be exceeded only after the Federal agency having jurisdiction over the matter has carefully considered the reason for doing so in light of the recommendations in this paper."

Arrangements have been made for the Council to follow the activities of the Federal agencies in this area and to promote the necessary coordination to achieve an effective Federal program. These have been described in a memorandum from the Chairman of the Council to the President, made public on October 13, 1960.

Control of Environmental Radioactivity

1.16 The objective of the control of population exposure from radionuclides occurring in the environment is to assure that appropriate RPG's are not exceeded. This control is accomplished in general either by restrictions on the entry of radioactive materials into the environment or through measures designed to limit the intake of such materials by members of the population. The most direct means of evaluating the effectiveness of control measures is the determination of the amount of radioactive material in the bodies of the members of exposed population groups. Although the determination of such body burdens may at times be indicated, in routine practice potential exposures will generally be assessed on the basis of either one or a combination of two general approaches: (1) calculations based upon known amounts of radioactive material released to the environment, and assumptions as to the fraction of this material reaching exposed population groups, or (2) environmental measurements of the amount of radioactive material in various environmental media.

1.17 Both of these general approaches involve the calculation or determination of actual or potential concentrations of radioactive material in air, water, or food. As stated above, controls should be based upon an evaluation of population exposure with respect to the RPG. For this purpose, the average total daily intake of radioactive materials by exposed population groups, averaged over periods of the order of a year, constitutes an appropriate criterion.

1.18 There is for any radioactive material a daily intake which is calculated to result, under specified conditions, in whole body or organ doses equal to a Radiation Protection Guide. The resulting value represents either the continuous or the average daily intake which would meet an RPG stated in terms of an annual dose. It is evident that the daily intake of radioactive material might fluctuate very widely around the average and still result in an annual dose which would not exceed the associated RPG.

1.19 The control of the intake of radioactive materials from the environment can involve many different actions. The character and import of these actions vary widely from those which entail little interference with usual activities, such as monitoring and surveillance, to those which involve a major disruption, such as condemnation of food supplies. Some control actions would require prolonged lead times before becoming effective, e.g., major changes in water supplies. For these reasons, control programs developed by the agencies should be based upon appropriate actions taken at different levels of intake. In order to provide guidance to the agencies in developing appropriate programs, this report describes a graded approach for the radionuclides considered, involving three ranges of transient rates of daily intake applicable to different degrees or kinds of action.

1.20 The objective of the graded scale of actions is to limit intake of radioactive materials so that specified RPG's will not be exceeded. Daily intakes varying within the total extent of all three ranges of intake might result in annual doses not exceeding a single RPG. However, in instances in which the daily intake is fluctuating above the average which would meet the RPG, it may not be possible to be assured that this will be the case. The actions outlined below would be appropriate, not only when intakes are fluctuating so as not to exceed a given RPG, but also in those situations in which valid reasons exist for the responsible agency to permit the possibility of doses which would exceed the RPG.

1.21 A suggested graded system of actions is outlined below. For each of the three ranges of transient rates of daily intake, specific values for which are given in the sections devoted to the specific radionuclides, the general type of action appropriate for the range is outlined.

RANGE I

Intakes falling into this range would not under normal conditions be expected to result in any appreciable number of individuals in the population reaching a large fraction of the RPG. Therefore, if calculations based upon a knowledge of the sources of release of radioactive materials to the environment indicate that intakes of the population are in this range. the only action required is surveillance adequate to provide reasonable confirmation of calculations.

RANGE II

Intakes falling into this range would be expected to result in average exposures to population groups not exceeding the RPG. Therefore such intakes call for active surveillance and routine control.

Surveillance

Surveillance must be adequate to provide reasonable assurance that efforts being made to limit the release of radioactive materials to the environment are effective. Surveillance must be adequate to provide estimates of the probable variation in average daily intake in time and location. Detection of sharply rising trends is very important. In some cases, because of the complexities of the environment, surveillance data may have to be sufficiently reliable to be used as a rough check on whether radioactive materials in the environment are behaving as expected. Not only the radioactive material in question, but also the

environment must be studied. Appropriate efforts might be made to obtain measurements in man as well as to study physical, chemical, and metabolic factors affecting uptake. Appropriate consideration should be given to other independent sources of exposure to the body (the same organs or different ones) to avoid exceeding RPG's.

Control

Routine control of useful applications of radiation and atomic energy should he such that expected average exposures of suitable samples of an exposed population group will not exceed the upper value of Range II. The sample should be taken with due regard for the most sensitive population elements. Control actions for intakes in Range II would give primary emphasis to three things: (1) assuring by actions primarily directed at any trend sharply upward that average levels do not rise above Range II, (2) assuring by actions primarily directed either at specific causes of the environmental exposure levels encountered or at the environment that a limit is placed on any tendencies of specific population segments to rise above the RPG, and (3) reducing the levels of exposure to segments of the population furthest above the average or tending to exceed Range II.

RANGE III

Intakes within this range would be presumed to result in exposures exceeding the RPG if continued for a sufficient period of time. However, transient rates of intake within this range could occur without the population group exceeding the RPG if the circumstances were such that the annual average intake fell within Range II or lower. Therefore, any intake within this range must be evaluated from the point of view of the RPG and if necessary, appropriate positive control measures instituted.

Surveillance

The surveillance described for intakes in Range II should be adequate to define clearly with a minimum of delay the extent of the exposure (level of intake, size of population group) within Range III. Surveillance would need to provide adequate data to give prompt and reliable information concerning the effectiveness of control actions.

Control

Control actions would be designed to reduce the levels to Range II or lower and to provide stability at lower levels. These actions can be directed toward further restriction of the entry of radioactive materials into the environment or the control of radioactive materials after entry into the environment in order to limit intake by humans. Sharply rising trend in Range III would suggest strong and prompt action.

1.22 The remaining sections of this report provide recommended values for the three ranges of transient rates of daily intake for iodine-131, radium-226, strontium-89 and strontium-90. The guidance is given in terms of transient rates of intake of radioactive material in micromicrocuries per day. The upper limit of Range II is based on an annual RPG (or lower, in the case of radioactive strontium) considered as an acceptable risk for a lifetime. However, it is necessary to use averages over periods much shorter than a lifetime for both radiation dose rates and rates of intake for administrative and regulatory purposes. It is recommended that such periods should be of the order of one year. It is to be noted that values in the remaining sections are much smaller than any single intake from which an individual might be expected to sustain injury.

1.23 The Federal Radiation Council has developed the guidance presented here to indicate a general philosophy relating the types of actions appropriate for the different ranges of intake. It is the responsibility of the individual Federal agency to determine the specific levels within this guidance which will actually be used for the various control efforts. In some cases, action which have been described in one range may appropriately be taken in another. The trend of environmental levels may be at least as important as the levels themselves. For example:

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(1) Environmental measurements indicating intake levels in Range I but rising sharply might suggest actions indicated here for Range II or Range III.

(2) Measurements indicating levels in Range III but known to be falling and, by action already taken, expected to be reduced further in the future might suggest no actions beyond those indicated here for Range I.

Derivation of Concentration Values

1.24 Although concentration values should be related to appropriate RPG's, in practice they are usually derived from intake guides. Thus, the principles which were discussed in connection with the guidance on daily intake are equally applicable in the case of concentration values. Specifically, determination of a concentration value will be based upon (1) the choice of a specific RPG and range of intake appropriate for the circumstances, and (2) allowance for the variability of intake possible without a resulting exposure exceeding the specified RPG.

1.25 The determination of concentration values involves additional factors, some of which are subject to wide variation. It is theoretically possible to calculate a single concentration value for ingestion to be the average concentration of a radioactive material present uniformly in all sources of ingestion which would meet a given intake value and its associated RPG. Such a concentration value however, would rarely be applicable in practice.

1.26 From the point of view of the control of general environmental contamination, radioactive materials may enter the human body from any one, or a combination, of the three environmental media: air, water, and food. Before an appropriate concentration value can be developed for an environmental medium in a specific situation, the relative contribution to total intake from the other media must be determined. In some situations this determination may result in simplification of the problem of providing a concentration value. For example, it might be observed that almost all of the intake results from ingestion of contaminated water. In this case, the determination of the concentration value would depend solely upon factors associated with the determination of water concentrations which will deliver a critical organ dose equal to the RPG.

1.27 In many instances, however, it is found that different environmental media contribute to the total intake. Combinations of intake from water and food or air and food may occur, and intake of the nuclides considered in this report may involve such combinations. Consequently, concentration values applying to the different sources of intake must take into account the relative contribution of each source to total intake. Even in those situations where food is the only source of intake of radioactive material, widely varying concentration values applying to different items in the diet may be appropriate. For example, in the case of intakes in Range III the necessity may arise for removal of a particular radionuclide from certain major contributors in the diet, or even elimination of certain dietary items containing high concentrations of the nuclide. The following are some of the considerations which may be involved in the determination of specific levels at which action such as the condemnation of certain food supplies would take place:

(1) Relative proportion of the total diet by weight represented by the item in question.

(2) The importance of the particular item in nutrition and the availability of substitutes having the same nutritional properties, or perhaps stockpiles of uncontaminated food.

(3) The availability of other possible control methods such as the removal of the radioactive material from the particular dietary item without affecting its quality.

(4) The half-life of the radioactive material.

(5) Other internal or external sources of radiation exposure to the same organ.

(6) Relative contribution of other dietary items to the total daily intake of the nuclide.

(7) Physical, chemical, and other factors affecting the relationship between intake and uptake of the nuclide.

(8) The time and effort required to effect corrective action.

In this connection, it is important to emphasize a point made in paragraph 1.18 in connection with guidance on intake. The agencies should bear in mind in establishing concentration values that it is possible to have wide fluctuations in daily intake which might still result in an annual average dose within the RPG. It can be readily seen that, since fluctuations in concentration guides can occur within a given intake value, even wider fluctuations can occur in concentrations in various foods and still result in an annual average dose that does not exceed the associated RPG. In any specific instance the greater the variation in concentrations, the more difficult it will be to estimate average intakes.

1.28 Because of the wide difference possible in concentration values applying to different environmental media and depending upon specified circumstances, the Federal Radiation Council has not made any specific recommendations on such values. The responsible Federal agencies should develop specific concentration values to apply to appropriate control actions as part of their operating criteria. The Federal Radiation Council will follow developments in this area and will promote the necessary coordination to achieve an effective Federal program.

SECTION II.—THE THYROID GLAND AND IODINE-131

Introduction

2.1 This section is concerned with the development of an RPG for the thyroid gland and guidance in connection with exposure of the general population to radioactive iodine. Currently, the major concern is environmental contamination resulting from fallout from the explosion of nuclear devices and the release of radioiodine during the use and processing of fuel for reactors. Fission products so formed may contain iodine-131, -132, -133, -134, and -135. The dose rate from the shorter-lived radionuclides (iodine-132, -133, -134, and -135 with half-lives ranging from approximately 53 minutes to 21 hours) will decrease rapidly with time in comparison with iodine-131 (half-life approximately 8 days). Consequently, guidance on intake of iodine-131 only is considered in this section. However, when the shorter-lived iodine nuclides are present and contribute significantly to the radiation dose received, they should be taken into account in accordance with the principles for summation of dose.

2.2 Like the naturally occurring stable isotope of iodine, iodine-131 when ingested or inhaled concentrates in the thyroid gland. Thus the thyroid gland receives a far larger radiation dose from iodine-131 than any other organ in the body. Radiation protection guidance to be used in connection with iodine-131, therefore, involves the determination of RPG's for the thyroid gland.

RPG for the Thyroid Gland

2.3 Report No. 1 specifies a Radiation Protection Guide for the thyroid gland of radiation workers of 30 rem per year. It specifies an annual whole body dose to individuals in the general population of 0.5 rem. The whole body guide is a factor of 10 below that specified for radiation workers. If one were to assume that the thyroid gland of individuals in the general population is no more sensitive when compared with the whole body than is the case in radiation workers, it might, from the point of view of the risk factor, be reasonable to use a value of 3 rem per year as an RPG for the thyroid of individuals in the general population.

2.4 This, however, may not be the case. Evidence is summarized below which has led the Council to the conclusion that in the development of RPG's for the thyroid gland it is necessary to take the position that a child's thyroid gland, relative to other organs of the child, is more sensitive to the carcinogenic effect of radiation than the adult thyroid gland compared to other organs of the adult. In the development of guidance on intake there is an additional factor which must be considered, i.e., the ratio between size of thyroid and intake of radioiodine in children is different from the ratio in adults.

2.5 In Report No. 1 (paragraph 2.19) it is noted that the child's thyroid is more sensitive to the carcinogenic effects of radiation than the adult thyroid. This conclusion is based upon several studies in recent years of the occurrence of thyroid carcinoma in children who had previously received therapeutic x-irradiation in the neck region for enlarged thymus or for other benign head and neck conditions. The incidence of thyroid carcinoma in these children was significantly higher than in control groups who had not been previously irradiated.

2.6 In these studies cancer of the thyroid was observed in children after exposures as low as approximately 150 rem. Similar effects have been observed in adults only at much higher dosages. Although these data do not provide a quantitative relationship, they do indicate that the child's thyroid is more sensitive to the carcinogenic effects of radiation than is that of the adult.

2.7 The RPG for the thyroid gland of radiation workers of 30 rem per year is twice the dose specified for other organs. This difference is based on two factors: (1) the evidence that the thyroid gland is adults is a particularly radioresistant organ, and (2) the needs for exposure of radiation workers to radioactive iodine in useful applications of radiation and atomic energy. If it were not for these considerations, no individual treatment would have been given the thyroid gland of radiation workers and it would have fallen into the category of other organs with and RPG of 15 rem per year.

2.8 From the point of view of the biological risk, therefore, the RPG for the thyroid of individuals in the general population, including children, should be less than 1/10 of 30 rem per year. On the other hand, it is logical to assume that the risk associated with a given radiation dose to the child's thyroid gland must be less than that associated with the same dose to his whole body. Thus the RPG for the thyroid of individuals in a population group could be higher than the 0.5 rem per year whole body dose without resulting in a greater biological risk.

2.9 The Council has reviewed data and studied atomic energy operations involving exposure of the thyroid gland of members of the general population. As noted in paragraph 2.1, such operations usually involve iodine-131. It finds that in general these operations can be conducted without undue difficulty in such a manner that the dose to the thyroid of individuals in the general population will not exceed 1.5 rem per year. It has been stated above that, since in the situation of environmental contamination individual doses are not usually known, this report will specify both individual doses and average doses to population groups. Therefore, the Council recommends RPG's for the thyroid gland of 1.5 rem per year for individuals and 0.5 rem per year to be applied to the average of suitable samples of an exposed group in the general population as representing a reasonable balance between biological risk and benefit to be derived from useful applications of radiation and atomic energy. If specific applications should be contemplated which cannot be conducted without exceeding the dose specified in the RPG, an individual assessment of benefit and risk must be made by the responsible agency in accordance with the principles previously outlined by the Council.

Guidance on Intake of Iodine-131

2.10 As a step in the development of guidance on intake of iodine-131 it is necessary to determine the average daily intake which would meet the RPG for averages in the general population. Among the factors to be considered are: (1) the weight of the thyroid gland, (2) the percent of the iodine intake which reaches the gland, and (3) the average retention time.

2.11 There is wide variation from one individual to another in the percent of an ingested or inhaled quantity of iodine-131 which appears in the thyroid gland. This percentage uptake is dependent upon such factors as the amount of stable iodine in the diet and the physiological state of the thyroid gland. In point of fact, certain pathological conditions in humans are manifest by an increase or decrease in the ability of the thyroid gland to concentrate iodine. A review of the data in the United States indicates that the normally functioning thyroid gland concentrates at 24 hours on the average approximately 30% of the initial quantity of iodine-131 taken into the body. The data also indicate that, while, as stated above, there is wide variation from individual to individual, there is no significant difference in the average between children and adults.

2.12 There is some evidence that suggests that iodine is metabolized more rapidly in the child than in the adult. This suggests the possibility of a somewhat shorter biological half-life. However, adequate information concerning the effective half-life of iodine-131 in younger children is not presently available. It is assumed, therefore that an effective half-life of 7.6 days is applicable for all age groups.

2.13 The average mass of the thyroid gland in adults is generally taken to be 20 grams. The mass of the gland in the child is, of course, less and depends upon the specific age. Since, as discussed above under the consideration of the RPG, the child is taken as the limiting case, the weight of the child's thyroid is considered as the limiting factor in the determination of guidance on intake. In calculating the average daily intake which would meet the RPG, the mass of the thyroid gland is taken as 2 grams. The resulting guidance on intake should, theoretically, be applied only to children and is subject to adjustment upward when applied only to adults. In many practical situations this adjustment will not be feasible. However, when agencies develop appropriate concentration values to refer to specific modes of intake (as between inhalation and ingestion) or to different dietary elements, this consideration should be kept in mind.

2.14 Using the known factors and the assumptions enumerated above, it can be calculated that an average daily intake of 80 micromicrocuries of iodine-131 per day would meet the RPG for the thyroid for averages of suitable samples of an exposed population group of 0.5 rem per year. As stated in Section I, it is appropriate to specify three ranges of transient rates of daily intake in order to provide guidance for the Federal agencies in the establishment of operating criteria. For this purpose, the value of 80 micromicrocuries per day has been rounded off to 100 micromicrocuries per day as being more in keeping with the precision of the data. Therefore, the following guidance on intake of iodine-131 to be applied to suitable samples of an exposed population group is recommended:

RANGE I	0 to 10 micromicrocuries per day
RANGE II	10 to 100 micromicrocuries per day
RANGE III	100 to 1,000 micromicrocuries per day

SECTION III.—BONE AND RADIUM-226

Introduction

3.1 Human experience with comparatively large quantities of radium in the skeleton was discussed in Report No. 1 (particularly pages 13-15) and the general practice of establishing radiation protection guides for occupational exposure to various radionuclides in the skeleton by relating them to radium-226 was endorsed. For this purpose, 0.1 microgram of radium-226 in the skeleton was adopted as a Radiation Protection Guide for radiation workers. This value has been in general use since 1941. The discussion in this section is concerned with the development of an appropriate Radiation Protection Guide for bone and of corresponding guidance on daily intake for control of exposures of the general population to radium-226.

3.2 The critical organ for radium in the body is the skeleton. It is assumed in this section that, except for radiation from natural sources other than radium and from medical x-rays, the total radiation dose to the skeleton is from radium-226 and its radioactive decay products. If other sources of radiation contribute significantly to the radiation dose to the skeleton, it is expected that they will be taken into account.

Considerations in the Development of RPG's

3.3 In the consideration of the risk side of the risk-benefit balance in the development of RPG's, Report No. 1 indicated several approaches to aid in the evaluation of the risk. Comparisons with occupational exposure guides and with exposures from natural background were discussed. Although neither provides a quantitative basis for the determination of population RPG's, each is useful. This is particularly true in the case of radium-226 because some data are available on both occupational and whole population environmental exposure.

3.4 The Radiation Protection Guide recommended by the Council for the whole body of individuals in the general population is a factor of 10 below the whole body guide for radiation workers. There are certain considerations, however, which indicate that the application of the same factor to the RPG for occupational exposure to radium-226 to obtain population RPG's may not provide the same degree of protection as in the case of the whole body. Some of these considerations are the following:

(1) The skeletal content required to give a particular radiation dose to the bone of a child is less than for the adult. Fortunately (from the point of view of simplicity of treatment of the problem), available data suggest that in an environment in which the average concentration of radium in the total diet, including water, is constant, concentrations of radium-226 in the skeletons of humans who have lived their entire lives in the environment are found to be relatively independent of age.

(2) The distribution of radium-226 in the skeleton of an individual who has lived his entire life in an environment constant with respect to small quantities of radium in his diet will be much more uniform than that of radium deposited in the skeleton as the result of occupational exposure. How the degree of hazard from radium in the skeleton might depend upon nonuniformity of distribution is not known.

(3) The radiation dose to the bone from radium deposited in the skeleton under constant environmental conditions is relatively constant throughout life. On the other hand, the dose resulting from deposition under controlled occupational exposure increases with length of exposure. Constant environmental exposure, therefore, results in a larger lifetime dose per unit quantity of radium-226 in the skeleton than occupational exposure in which the specified quantity is assumed to be reached only near the end of life. Furthermore, because of the long latent periods characteristic of carcinogenesis at low dose levels, it appears reasonable to as-

sume that the earlier in life the radiation dose from radium is received the more likely the individual will live until any carcinogenic effect can become manifest.

3.5 Turning to the second approach, that of comparing the radiation doses to the skeleton from radium-226 with radiation doses normally received from all natural sources of radiation, it is immediately apparent that bases for comparisons are, at best, uncertain. In physical units of radiation dose (e.g., rads) the dose to the skeleton from all natural sources of radiation averages between 0.1 and 0.15 rads per year. The quantities of radium-226 in the adult skeleton which, with its radioactive decay products, are required to give corresponding physical doses range from about 0.003 to 0.005 micrograms. There is insufficient information on the relative biological effectiveness of the radiation from radium to attempt a realistic conversion of this dose in rads to the skeleton from radium and its decay products into rems.

3.6 Because of the uncertainties involved in comparing radiation from radium with total radiation to the skeleton from natural sources, it is useful to consider the natural occurrence of radium in the skeleton. In most areas of the United States, the radium content of the adult human skeleton is found to range from about 0.0001 microgram of radium-226 to some two or three times this amount. In such areas, the radium content of drinking water is generally so low that the skeletal content is believed to be almost entirely due to the occurrence of sufficient radium-226 in food to result in a daily intake of from 1 to 2 micrograms. In some areas, however, concentrations of radium-226 in drinking water are sufficiently high to result in much larger daily intakes and correspondingly higher amounts in the skeleton. There are communities in which unusually high radium concentrations in supplies of drinking water result in adult skeletal levels which range upward to amounts of the order of 0.001 microgram. A program is underway to determine whether any biological effects of such amounts of radium can be detected by epidemiological studies with methods currently available. However, it is expected that a number of years will be required to reach any useful conclusions.

3.7 These approaches give two reference points for use in comparison of biological risk with reasons for acceptance of risk. In the case of radium, reasons for acceptance of risk involve consideration of the difficulty of meeting possible RPG's and the impact of this difficulty on industry and the community. Before this comparison can be made it is necessary to consider the relationship between environmental levels and body content of radium since this relationship vitally affects the difficulty of meeting any RPG.

3.8 The data which are most relevant to the determination of the relationship between environmental levels and body content are the observations of the relationships between concentrations of radium-226 in community water supplies and corresponding quantities in the skeleton of persons using the water. Estimates of average concentrations in normal United States diets and corresponding average skeletal contents, while less firmly supported, are reasonably consistent with these observations. These data indicate that on the average the concentration of radium-226 in the skeleton of individuals of any age does not exceed a value corresponding to a total quantity in the adult skeleton of about fifty times the daily intake.

3.9 The Council has considered operations involving the release of radium-226 to the environment. These can be conducted, in the opinion of the Council, without undue difficulty in such a manner that average daily intake of radium-226 in an exposed population group will not exceed 20 micromicrograms. The Council has also reviewed available data on radium-226 concentrations in public water supplies in the United States. The overwhelming majority of the population consumes water from supplies corresponding to daily intakes of radium-226 well below this level. In those situations where this may not be the case, the extremely small risk associated with intakes above this level should be considered by the appropriate authorities in light of difficulties which may be associated with any modifications in the water supply.

3.10 In view of the above considerations, the Council recommends as an alternate RPG for bone for individuals in the general population a skeletal concentration of radium-226 corresponding to 0.003 microgram in the adult skeleton. The RPG to be applied to the average of suitable samples of an exposed population group is a skeletal concentration of radium-226 corresponding to 0.001 microgram in the adult skelton. These values are considered by the Council to represent an appropriate balance between biological risk and reasons for acceptance of risk.

Guidance on Intake

3.11 The relationship between environmental levels and body content referred to in paragraph 3.8 indicates that an average daily intake of 20 micromicrograms of radium-226 corresponds to the RPG for suitable samples of exposed population groups. Therefore, the Council recommends the following guidance on transient rates of daily intake of radium-226 to be applied to the average of suitable samples of an exposed population group:

RANGE I	0 to 2 micromicrograms per day
RANGE II	2 to 20 micromicrograms per day
RANGE III	20 to 200 micromicrograms per day

It is important to emphasize that the risk associated with this intake guidance is, in the opinion of the Council, much lower than has generally been considered. The skeletal content associated with a daily intake of 20 micromicrograms is about an order of magnitude lower than that which would be implied by extrapolation from current occupational standards for radium. The Council considers, however, that the data from the environmental studies, though limited, represent a more valid basis for derivation of the relationship between continuous exposure and body content.

SECTION IV.—BONE MARROW, BONE AND RADIOISOTOPES OF STRONTIUM

Introduction

4.1 In this section, RPG's for bone marrow and bone and guidance for the protection of individuals in the general population against excessive exposure to radioisotopes of strontium are developed. The chemical and physical characteristics are such that, for this purpose, our principal interest is in the irradiation of bone and bone marrow as the result of deposition of strontium-90 and strontium-89 in the skeleton. Because such deposition results from the occurrence of the radioisotopes in ingested food and water and in inhaled air, protection is achieved by limiting average concentrations in food, water, and air used by humans. Thus, while the hazard to the individual results from radiation emitted over long periods of time by material actually in his skeleton, for purposes of control it is necessary to specify guidance on intake of the isotopes which will not result in excessive irradiation of body tissues. In applying such guidance to actual environmental situations, it is necessary to convert intake values to concentration values applicable to specific items in the total diet (both food and water) and in inhaled air according to the general principles in Section I.

Derivation of RPG's for Bone Marrow and Bone

4.2 Report No. 1 recommended an RPG for the whole body of individuals in the general population of 0.5 rem per year as representing an appropriate balance between the requirements of health protection and of the beneficial uses of radiation and atomic energy. Basic to the considerations involved in a guide for whole body dose were the factors associated with exposure of bone marrow. Thus RPG's for the bone marrow of 0.5 rem per year for individuals in the general population and 0.17 rem per year as an average to be applied to suitable samples of an exposed population group are considered by the Council to represent a similarly appropriate balance of benefit and risk.

4.3 Experience indicates that bone is relatively insensitive to X and gamma radiation when compared with bone marrow. Groups exposed to X and gamma radiation in which a higher than normal incidence of leukemia has been observed have not shown corresponding increases in bone tumors. Although these data do not provide a quantitative basis for relating the sensitivity of bone and bone marrow they do indicate that from the point of view of the risk it is reasonable to permit a larger dose to bone than to bone marrow.

4.4 In the case of strontium-90, the dose rate to bone from a given skeletal content is three times the average dose rate to bone marrow. Other beta emitters of similar distribution in bone and comparable energy would yield similar factors. The Council considers that Radiation Protection Guides for the bone of 1.5 rem per year for individuals in the general population and 0.5 rem per year as an average to be applied to suitable samples of an exposed population group represent an appropriate balance between the requirements of health protection and of the beneficial uses of radiation and atomic energy.

The Development of Guidance on Intake of Strontium-89 and Strontium-90

4.5 The considerations involved in the development of guidance on intake of strontium-89 and strontium-90 are summarized in the following paragraphs. The guidance is applicable only under the conditions specified in their derivation, i.e. continous exposure to radioactive strontium in food, water, and air throughout the lifetimes of the individuals involved and under normal peacetime operations. The guidance is based on the assumption that the exposure source it covers is the only source of exposure of the skeleton to radiation other than natural background and medical and dental exposures. Where actual exposure involves both strontium-89 and strontium-90, or where the skeleton is also exposed to significant amounts of radiation from other sources, such as barium-140 or abnormal quantities of radium-226, it is expected that these will be taken into account. Likewise, where there is significant intake through both ingestion and inhalation, it is expected that the total deposition in the skeleton will be considered.

Biological Effects

4.6 No effects in humans attributable to the ingestion or inhalation of radioactive strontium have been observed from the levels of radioactive strontium which have occurred in the environment nor does it appear from our present knowledge that it would be possible to observe any. Consequently, evaluation of the hazard to humans is primarily dependent upon extrapolation and dose interpolation from the effects on experimental animals exposed to far greater quantities of radioactive strontium, or from the effects of other sources of radiation on humans.

4.7 Experimental animals given large doses of radioactive strontium have developed osteogenic sarcomas, and it might be expected that this would occur in a human group under similar circumstances

4.8 Some small laboratory animals have developed leukemia following large injected doses of radioactive strontium, presumably from irradiation of the bone marrow, although the causative relationship is not clear. Extrapolating animal experience to humans is very uncertain. Data obtained as a result of exposure of humans to external radiation indicate that at levels of exposure much higher than those under consideration here, the bone marrow is significantly more radiosensitive than the bone.

Metabolic Factors

4.9 Ingested strontium is concentrated in the mineral skeleton, as is calcium and several other alkaline earth elements. Under equilibrium conditions, essentially all strontium in the body is in the skeleton. The mineral skeleton appears during intra-uterine life, and increase in mass until about age twenty years. Another process of bone metabolism is the continuous replacement of the mineral portion at a low rate on a microscopic scale throughout life. Thus, there is a continuous exchange of mineral elements between the environment and the blood, and a continuous exchange between the blood and the skeleton.

4.10 Strontium is similar but not identical biochemically to calcium. Therefore, although some ingested strontium is deposited in bone in a manner similar to calcium, there are metabolic mechanisms which perform some discrimination between the two elements, so that their relative concentration when deposited in bone is different from their relative concentration in the diet. The similarities in metabolic pathways of strontium and calcium make it meaningful and convenient to use ratios of the two elements in evaluating the deposition of radioactive strontium.

4.11 Newly formed bone has about the same strontium to calcium ratio as is in the blood circulating at the time of formation. There is some discrimination against strontium between ingested material and blood, which results primarily from preferential renal excretion of strontium, but which may also be influenced by preferential absorption of calcium through the gut.

4.12 Data on humans and laboratory animals indicate rather well that there is a discrimination factor against strontium of about four in the strontium to calcium ratio between diet and bone. Although some experimental evidence suggests that there may be periods during infancy and adolescence in which the discrimination factor is less than four, observations of the ratio of natural strontium to calcium in the human skeleton as a function of age indicate no practical difference. The strontium to calcium ratio of the embryo and fetus is affected not only by the maternal discrimination factor of four between diet and blood, but by a placental discrimination factor of about two. The resultant discrimination between maternal diet and fetal bone would therefore be about eight under conditions of equilibrium. Presently, the observed occurrence of strontium-90 in fetal bone is somewhat less than predicated for conditions of equilibrium, probably because of a calcium contribution from the maternal skeleton, which is not now in equilibrium with the strontium-90 in the diet.

4.13 Under constant intake conditions throughout life, and with the exception of the infant, whose skeletal level of strontium would be in transition from the prenatal to the postnatal equilibrium values, evidence indicates that the distribution of strontium in bone mineral would be reasonably uniform both throughout the bone and throughout life. For example, measurements of the ratio of natural strontium to calcium in over 200 skeletons of persons ranging in age from stillbirths to eighty years, reported by the Medical Research Council of the United Kingdom, November 14, 1960, indicate that the mean ratio of strontium to calcium in humans does not increase more than about 25 percent after the age of two years.

Radiation Dose Factors

4.14 Strontium-90 in the skeleton exists in secular equilibrium with its daughter, yttrium-90. These nuclides emit beta radiation with a maximum range of about six millimeters in bone and one centimeter in soft tissue. For a non-uniform distribution of the nuclides in bone, they would deliver a substantially more uniform radiation dose than a similarly distributed alpha emitting material. When the macroscopic distribution of strontium-90 in bone is reasonably even, the radiation dose can be considered as essentially uniform.

4.15 Because of the greater range of beta radiation, bone marrow would receive a greater portion of the radiation dose from strontium-90 than from an alpha-emitting material in bone. The dose to a small bit of bone marrow surrounded by a large mass of dense bone would approach the dose to the bone. However, the average bone marrow dose from strontium-90 would be substantially less than the bone dose. Similar considerations apply to strontium-89.

Application of RPG's to Strontium-90

4.16 The Council has considered the basis for evaluation of the biological risk associated with exposure of population groups to strontium-90 under the conditions stated in paragraph 4.5. This consideration included comparison with the RPG for bone marrow and bone recommended in paragraphs 4.2 and 4.4 and comparison with the alternate guide for bone in Section III.

4.17 For those radionuclides for which the skeleton is considered to be the critical organ, occupational standards commonly have been derived by estimating body burdens considered to be no more hazardous than 0.1 microgram of radium. Two of the reasons for adopting this approach were: (1) experience with radiation injury to the human skeleton is largely limited to cases in which relatively large quantities of radium have been introduced into the skeletons of adults, whether as a result of occupational exposure or for medical reasons; and (2) it is considered that, in general, the distribution of radionuclides deposited in the skeleton under occupational conditions of exposure may be of such a nature as to make direct comparison with X and gamma radiation uncertain.

4.18 In addition to the considerations which normally arise in making comparisons between exposures of population groups and exposures for occupational reasons, the manner in which occupational standards for strontium-90 have been derived appears to make them less appropriate as a basis for comparison than the RPG's for bone marrow and bone given in paragraphs 4.2 and 4.4. Basically, derivation of occupational standards for strontium-90 has involved experimental determination of relative quantities of strontium-89 and radium-226 in small laboratory animals required to produce biological damage considered to be comparable. It was then assumed (for lack of more certain information) that, except for an adjustment to allow for the higher retention of radon in the human skeleton, the same ratio would hold for man. The corresponding ratio for strontium-90 and radium-226 was estimated to be twice as large as that for strontium-89 and radium-226 because the combined energy emitted by strontium-90 and yttrium-90 per disintegration of strontium-90 is approximately twice that emitted per disintegration by strontium-89.

4.19 This estimate of the relative quantities of strontium-90 and radium-226 required to produce radiation hazards or effects considered to be equivalent for purposes of radiation protection to those of radium was found to depend upon the conditions of the experiment, particularly dose rate, and upon the effect chosen as a measure of injury. The ratios chosen as representing the relative hazards of strontium with respect to radium were those corresponding to massive acute doses. The experimental observations indicated that for chronic exposure at

lower dose rates the relative hazards of radiostrontium are smaller by factors which range downward to less than one-tenth and perhaps to one-hundreth of those observed for acute doses.

4.20 Studies of individual and relative radiotoxicities of radium-226 and strontium-90 using large laboratory animals are now in progress. It is expected that such studies will not only provide better comparisons of the relative hazards of strontium and radium to experimental animals under conditions more nearly approaching those of interest, but will provide better independent data on the nature and degree of hazard from radioactive strontium. In addition, the use of larger animals and several species of animals is expected to reduce the uncertainties inherent in extrapolation to man. However, the nature of such investigations is such that periods of time comparable to the normal lifetimes of the animals are required to obtain a sufficient amount of useful information on which to base sound conclusions.

4.21 It appears that comparisons with the bone marrow and bone RPG's given in paragraphs 4.2 and 4.4 can be made with less uncertainty and are more meaningful than comparisons with occupational standards for strontium-90 which have been, in turn, based upon comparisons with radium-226. It is assumed that the total intake of strontium-90 by individuals is such that the average ratio of strontium-90 to calcium in the blood is constant throughout life. This is considered to be approximately true if the ratio of strontium-90 to calcium in the total diet (that is, in the total amount of food and water ingested by the individual) remains constant. In line with the principles in Report No.1 of control of exposure of members of the public to radiation, ratios may be averaged over periods of time of the order of one year.

4.22 Under the conditions assumed, experience with stable strontium in the normal diet as well as such data on the uptake of radioactive strontium from the diet indicate that the distribution of strontium-90 in the skeleton will be reasonably uniform. The ranges of the beta rays from strontium-90 and its radioactive decay product, yttrium-90, are sufficiently large that the microscopic distribution of radiation dose to the bone (except for losses of radiation near the surface) will be even more uniform. Under these conditions, the RBE (relative biological effectiveness) of the beta radiation does not differ markedly from that of X and gamma radiation of quantum energy in the range between two hundred and several hundred Kev.

4.23 It has been estimated that the average dose to bone marrow from strontium-90 and yttrium-90 in a skeleton of average density is about one-third of the dose to bone. Data on experimental animals indicate that the protection of a small portion of bone marrow from a high dose of radiation may markedly lower the incidence of leukemia. This suggests that in the case of non-uniformity of radiation dose to the bone marrow, the average dose is a more meaningful index of hazard than the maximum local dose and that, for a given average, a non-uniform distribution of dose may be less hazardous than a uniform distribution. Thus, the RPG's for bone marrow and bone recommended in paragraphs 4.2 and 4.4 appear appropriate as a basis for the evaluation of the risk associated with exposure of population groups to strontium-90.

4.24 The Council has emphasized, however, that in the application of general RPG's, both the risk and the reasons for accepting the exposure should be considered. The Council has, therefore, reviewed past and current activities resulting in release of strontium-90 to the environment, and given some consideration to future developments. This review indicates that in general these activities can be conducted without undue difficulty at exposures lower than those corresponding to the RPG's. Therefore, in the development of the guidance on intake, doses corresponding to one-third the RPG's for bone marrow and bone to be applied to the average of suitable samples of an exposed population group have been used.

Guidance on Intake of Strontium-90

4.25 As a step in the development of guidance on intake of strontium-90, it is necessary to determine the average daily intake of strontium-90 which would correspond to doses of one-third the RPG's to be applied to suitable samples of an exposed population group. The nature of the relationship between the ratio of strontium and calcium in the human diet and in the human skeleton has been discussed in paragraphs 4.9 - 4.13. The data referred to in paragraph 4.13 not only indicate that the ratio of natural strontium to calcium in the skeleton does not increase significantly with age but they show that within a general geographical area natural differences in dietary habits do not result in a large spread in the values observed in the skeletons of individuals of all ages.

4.26 The average ratio of strontium to calcium in the human skeleton is estimated to be about one-fourth of the ratio in the diet. On this basis, a continuous dietary ratio of 200 micromicrocuries of strontium-90 per gram of calcium is estimated to result in a skeletal concentration of 50 micromicrocuries per gram of calcium and to produce radiation doses, averaged over any age group of a uniformly exposed population group, corresponding to approimately one-third of the appropriate RPG's. This level in the maternal diet would give about one-sixth the RPG to the prenatal individual.

4.27 The similarity between the chemical properties of strontium and those of calcium makes the average ratio of strontium-90 to calcium in the diet a useful device in the development of guidance on intake. In some situations, it may be desirable to consider concentrations of strontium-90 and calcium in individual items of diet. However, in general it is useful to use intake values based on average calcium content of the diet.

4.28 Appropriate intake values will depend upon the composition of the diet and the average consumption. The minimum calcium requirement in the American diet is considered to be of the order of one gram per day. The average intake may be considerably in excess of this amount, although in some areas it is found to be somewhat less. For the derivation of intake guidance, the Council adopts the figure of one gram of calcium per day. On this basis, a continuous dietary intake of 200 micromicrocuries per day would generally correspond to the radiation doses discussed above.

4.29 It is therefore recommended that the following guidance on transient rates of daily intake of strontium-90 to be applied to the average of suitable samples of an exposed population group be adopted for normal peacetime operations:

RANGE I	0 to 20 micromicrocuries per day
RANGE II	20 to 200 micromicrocuries per day
RANGE III	200 to 2,000 micromicrocuries per day

Strontium-89

4.30 Occupational standards have related body burdens of strontium-89 and strontium-90 in such a manner as to permit the same total absorption of energy by the skeleton from one as from the other. This results in a body burden for strontium-89 two times that for strontium-90. Because of the shorter half-life of strontium-89, 52 days as compared to 27 years, the corresponding ratio of permissible concentrations has been estimated to be about 100.

4.31 Because of the manner in which the Council has derived guides for exposures of population groups to strontium-90, it is not possible to relate the two on the basis of energy comparison alone with as high a degree of confidence as is involved in the development of the guide for strontium-90. The guides for strontium-90 depend upon the validity of the assumption of reasonable uniformity of concentration in the skeleton. Because of the relatively short half-life of strontium-89, and hence the relatively short time in which strontium-89 atoms exist in the body, the distribution of dose is necessarily much less uniform than that from strontium-90. It is, however, possible to derive, by comparison with strontium-90, guides which represent no greater hazards than those for strontium-90 and which are not excessively restrictive.

4.32 For this purpose, we take advantage of the current practice of permitting population exposures to be averaged over periods of up to one year. The maximum dose rate will be experienced in areas in which new bone is being formed. Our objective is to limit the dose in any one year to the value which would have been permitted if the radioactivity were strontium-90. For simplicity, consider a section of "bone" of reasonable size and suppose that it has been "formed" of calcium, strontium-89, and other appropriate elements by normal process of metabolism in a period of time short in comparison with the half-life of strontium-89. It may be shown that the decay rate of strontium-89 is such that the average dose rate to the bone over a period of one year after formation will be only one-fifth of the initial dose rate.

Because the average energy absorbed per disintegration of strontium-89 is only half that per disintegration of strontium-90 and its yttrium daughter, in this hypothetical case ten times as much strontium-89, measured in terms of activity, could be permitted as of strontium-90 without increasing the average dose in one year. In subsequent years, of course, the dose to this section of the bone would be essentially zero.

4.33 It is apparent that if such a section of bone were to be built up slowly instead of instantaneously, the average dose to this section of the bone during the ensuring year would be somewhat less. This may be demonstrated in the following manner. If the section of bone added is reduced in thickness, a larger fraction of the total radiation emitted by the strontium-89 in this section escapes to adjacent material. While this escape may be compensated for in part by absorption of radiation from adjacent material, if such adjacent material is older than the section under consideration, it must have a lower concentration of strontium-89 and, hence, the compensation cannot be complete.

4.34 On the basis of the above argument, since strontium-89 follows the same metabolic pattern as strontium-90, guidance on intake of ten times that used for strontium-90 will result in dose rates to bone marrow and bone which, in any area of the skeleton, will not exceed in any one year those permitted from strontium-90. While these dose rates represent hazards which, over a period of years, are certainly much less than those from continuous exposure to strontium-90 at one-third the RPG, the reasons for accepting comparable risks from strontium-89 are generally less.

4.35 Therefore the following guidance on transient rates of daily intake of strontium-89 to be applied to the average of suitable samples of an exposed population group is recommended for normal peacetime operations:

RANGE I	0 to 200 micromicrocuries per day
RANGE II	200 to 2,000 micromicrocuries per day
RANGE III	2,000 to 20,000 micromicrocuries per day

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REPORT NO. 3

health implications of fallout from nuclear weapons testing through 1961

May 1962

Report of the

FEDERAL RADIATION COUNCIL

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REPORT OF THE FEDERAL RADIATION COUNCIL

HEALTH IMPLICATIONS OF FALLOUT FROM NUCLEAR WEAPONS TESTING THROUGH 1961

The Federal Radiation Council has considered available information on radiation doses and possible health effects of atmospheric nuclear weapons testing. Before discussing the estimates made in this report in detail, it is appropriate to point out the difficulties of being precise in this field.

Although a large and expanding program for measuring radiation levels at a number of locations throughout the United States has been in effect for a number of years, the application of such data to the whole country, to an extended time period, or to the entire population involves assumptions than can not be completely validated. Furthermore, while a considerable body of information has been accumulated on the effects of radiation on animals and man, the possible effects of low doses delivered at low dose rates are insufficiently known to permit firm conclusions about the extremely low exposures resulting from fallout. Current experimental techniques are not good enough to detect biological effects at the low levels of worldwide fallout from nuclear tests.

Any possible manifestations resulting from fallout radiation will not be unique, for all of the diseases and disabilities known to be caused by radiation also occur for other reasons. Whatever effects might be produced by fallout could only be reflected in statistical increases in the number of conditions already present in the population. Any individual effects would be so diluted by space and time that they would not be recognizable among the much larger number of identical effects arising from other causes, among which they would be interspersed.

Finally, any proper understanding of estimates in this field must take into account the many different ways in which similar or even identical data can be expressed. Many of the apparent differences among scientists arise from different forms of presentation. Two approaches have been used. One estimates the risk of damage to a single person. This risk is extremely small in comparison with others which people normally accept. The second approach considers possible effects on a large population for a year or a generation or for several generations totaling hundreds of years. Even a very small proportion of affected individuals will, in a very large population for a long period of time, amount to an impressive total number of individuals.

Estimated Radiation Exposure from Testing

Any consideration of possible health effects from fallout must begin with the radiation doses to which people are exposed as a result of such tests.

A sharp distinction must be made between the devastating effects of "local" fallout in a nuclear attack on an unshielded population and the effects of fallout from weapons testing. Weapons testing creates far smaller total amounts of fission products so that its fallout is far less than that which would result from nuclear war. Furthermore, the tests are planned to avoid local fallout or to confine it to locations where it will have minimal effects. Hence, in weapons testing the problem is largely confined to delayed fallout which decays greatly in the upper atmosphere and is dispersed at low concentrations over the earth's surface. This report is concerned primarily with the effects of such delayed fallout.

Dose estimations must take into account exposure from all sources; external, and internal through ingestion of food and water and inhalation. Some radioactive elements may concentrate to different extents in various parts of the body. Those which tend to concentrate in a certain organ will selectively irradiate that organ. Thus a thyroid dose, for example, represents the sum of the whole-body dose from a variety of substances plus the extra dose from iodine-131, an element which tends to concentrate in the thyroid gland. In addition, some elements are taken up more effectively at one age than another. For example, the proportion of strontium-90 retained in the growing bones of children is greater than that retained in the bones of adults ingesting the same foods. Furthermore, different sources of radiation give off different kinds of radiation having different biological effects, so that doses cannot be directly compared. These points should indicate the difficulty of referring to any one exposure level from a particular source without identifying what kind of a dose and what part of the body is involved.

Estimates of doses from fallout from tests through 1961 in millirems, a unit of ionizing radiation dose, are given in Table I and discussed further in Appendix "A". Because of uncertainties and the variety of necessary assumptions, these estimates are expressed as ranges of values within which the average exposure over the United States is expected to lie. The values given apply to the United States, and are somewhat higher than those for most of the rest of the world. Doses to the whole-body and reproductive cells represent an average for all age groups in the entire population. Doses to bone and bone marrow are average values for those who were infants at the time of highest concentrations of the particular isotopes irradiating these organs; values averaged for all age groups will be lower.

The half-life of radioactive iodine, the principal source of the thyroid dose, is only 8 days and the peak dose rates persist for a relatively short period of time. For this reason thyroid doses are not included in the table. Doses to the thyroid from the major past tests were estimated to have ranged from 100 to 200 millirems per year during and immediately following periods of testing. These values apply only to individuals who were infants at the time of highest concentration of radioactive iodine. The average value for all age groups was about a tenth as much. Although data from which thyroid doses during 1957-58 can be estimated are limited, it is likely that there was much geographic variation, and in some limited areas of the United States the average thyroid doses were probably many times the national average.

The whole-body dose due to the carbon-14 produced by all tests through 1961 has been included but not separately listed in Table I. It is estimated to total from 10 to 15 millirems during the first thirty-year period. The dose rate will decrease much more rapidly than would be predicted on the basis of the carbon-14 radioactive half-life of 5,700 years because of the absorption of the radioactive carbon dioxide from the atmosphere into the ocean. After about 200 years the dose rate from carbon-14 will have been reduced to a total of about 0.75 millirem during a thirty-year period.

To put these dose levels in some perspective, Table I compares them with exposures from natural background and with the Radiation Protection Guides of the Federal Radiation Council. The comparisons indicate that doses from fallout have generally been a small fraction of the Guides for population groups.

Background radiation arises from naturally radioactive materials such as carbon-14 and potassium-40 in the human body, radium in the earth's crust, and cosmic radiation from outer space. Man has always been exposed to these radiations. Natural background radiation varies from place to place, both with elevation and with radioactive content of local materials. In the United States these values have been observed to range from 70 to 200 millirems per year. The value for background radiation given in Table I is a weighted average for the entire United States population.

The estimated values given in Table I for whole-body exposures from fallout are considerably less than the exposures from natural sources. Over a period of 30 years the average whole-body dose from all testing through 1961 will be between 60 and 130 millirems compared to 3,000 millirems from background. Thus testing through 1961, including the contribution from carbon-14, will, over this thirty-year period, increase exposures over natural background by less than five percent. Seventy-year average bone doses, when similarly compared, are increased less than ten percent. Any further testing will, of course, increase the exposure.

The fact that exposure from some sources is generally accepted without question should not in itself be a reason for accepting exposure to added levels of man-made radiation. However, comparison of exposure levels with those of natural background does provide some indication of the significance of increases from fallout. One normally considers variation in exposure from natural sources to be of little significance. For example, a resident of the East Coast contemplating a move to a high-altitude location in the West is unlikely to know or attach any importance to the fact that his exposure to background radiation will be appreciably increased—more than twenty-five percent at elevations above one mile.

Another basis of comparison is the radiation exposure received from medical diagnostic procedures in the United States. It has been estimated that a person in the United States will accumulate a genetically effective dose of the order of 1,000 millirems over a thirty-year period. There are, however, wide fluctuations in the exposures to the reproductive cells from the diagnostic procedures.

Estimates of Biological Effects

Much available evidence indicates that any radiation is potentially harmful. However, effects become increasingly difficult to demonstrate below 10,000 millirems, and impossible to detect by present techniques at the very low dose levels from fallout. Nevertheless, it is virtually certain that genetic effects can be produced by even the lowest doses. These effects in the children of exposed parents and all future generations may be of many kinds, ranging from minor defects too small to be noticed to severe disease and dealth.

In the case of somatic effects, i.e., effects directly on the persons exposed, the evidence is insufficient to prove either that there is a dosage level below which no damage occurs (the "damage threshold" hypothesis) or that there is some risk of damage at any dosage level, no matter how low (the "no threshold" hypothesis). It may well be that some effects are of one kind, some of the other. Dose rate is important; a protracted dose is much less effective than the same total dose given in a short time.

Estimates have been made by national and international groups of scientists of the number of possible adverse health effects that might occur from various exposure levels. Tables II and III apply some

of these estimates to the exposure levels from all testing through 1961 to indicate the possible adverse health effects in the United States population that might result from this testing. United States figures have been used because knowledge of dose levels and of health effects occurring in the absence of testing is more complete for this country than on a worldwide basis. For convenience in expressing the concepts and calculations in this report, the population of the United States has been taken as approximately one-tenth of the population in the same latitudes of the northern hemisphere, and as one-twentieth of the population of the entire world. The figures in Table II on the possible number of adverse health effects from testing through 1961 may be multiplied by 10 to provide a rough estimate of comparable worldwide effects with the exception of carbon-14, for which a factor of approximately 20 must be applied.

Table II and Appendix "B" give numerical estimates of the effects of fallout on one category of genetic effects—severe physical and mental defects. This category includes the hereditary component of such things as congenital malformations, blindness, deafness, feeblemindedness, muscular dystrophy, hemophilia and mental diseases.

In Table II the estimated numbers of radiation effects are given as three values. The upper figure is the best estimate based on radiation-induced mutation rates in mice, and on the spontaneous incidence of these defects in man. The other figures represent the range within which the true value may reasonably be expected to lie.

As shown in the table, about ten percent of the number that may result in all time from weapons tests through 1961 are estimated to occur in the first generation—the children of parents exposed to this fallout. The remaining ninety percent occur in decreasing numbers in succeeding generations. Somatic effects appear only in the irradiated individual himself, and not in his offspring. The manifestations of particular concern are leukemia and other types of cancer.

The radiation dose from carbon-14 is spread over an enormous period of time extending through many thousands of years. The number of mutations from carbon-14, when exposure over all time is considered, is estimated to be greater than from other radioactive elements produced in nuclear detonations. These mutations will, however, be distributed over a much longer time with a much smaller number in any one generation.

In addition to the gross defects listed in Table II, there may be an unknown but probably a considerably larger number of mutations with less obvious effects such as minor physical abnormalities, mild diseases, impairment of physiological functions, and reduced resistance to infection or other stresses of life. Part of this damage will result in a lowered probability of survival at various ages.

Reduced viability of this kind has been consistently found in mouse experiments. The best data on mice are for the infant and embryonic deaths. To the extent that mouse data can be applied to man, the results indicate that the radiation-induced mortality of embryos and infants in the first generation after irradiation is probably larger, perhaps five times larger, than the number of induced defects of the type estimated in Table II. Numerical estimates are not given for such effects because of uncertainties as to the comparability of these effects in mice and humans. This is the viewpoint of those who have done much of the experimental work in this field.

Mutations which have a mild effect on the individual may cause substantial damage in the aggregate. This is because the mildness permits these mutations, such as slight reductions in viability and other less obvious effects, to persist in the population longer than mutations with severe effects, and thus to affect a correspondingly greater number of persons. There are no data which would permit these effects to be assessed with sufficient accuracy to permit numerical estimates.

If, however, numerical estimates are made of all these genetic effects, both those which are likely and those which are more speculative, the aggregate of these estimates when counted as the total number of individuals affected throughout the world in future generations leads to very large numbers. Likewise, large numbers can be obtained when other effects or deaths from any cause are totaled over large populations and many generations. On the other hand, it must be emphasized again that whatever the genetic effects of fallout radiation from weapons testing through 1961 may be, the total effect will certainly be considerably less than that occurring inescapably from background radiation. This, in turn, is considerably less than the effects from other factors which determine the total natural mutation rate.

Estimates for two kinds of somatic effects, leukemia and bone cancer, are given in Table III. As mentioned earlier, it is not known whether or not there is a threshold dose below which these diseases are not produced. If a threshold exists, fallout radiation may produce no additional cases, and the lower limits of zero reflect this possibility.

The upper estimates in Table III are made by assuming the effect of a low dose, delivered at a low dose rate, to be proportional to the effect of a high dose delivered at a higher dose rate. The estimates for the upper limits are probably too high because no allowance had been made for the possibility that a given dose is less effective when received slowly over a long period of time. Thus the range of numbers given in Table III is reasonably certain to bracket the correct value.

There are other possible somatic effects of radiation such as malignancies (other than leukemia and bone cancer) and general effects such as life shortening. Among these malignancies is cancer of the thyroid, a possible effect from exposure to radioiodine. Table III includes no data on the possible incidence of this effect because estimates, like those recognized by national and international groups of scientists for possible leukemia and bone cancer effects, have not been made for cancer of the thyroid. However, from what little is known about the effect of radioiodine, including data obtained from human exposures at very high levels, the likelihood of any possible thyroid effects has been considered to be about the same as other malignancies for comparable exposures. Even less information is available as to possible increases in all these other effects than is available for leukemia and bone cancer.

To put these estimates of possible adverse health effects in some perspective, Tables II and III also include the total number of these same effects occurring in the United States from all causes.

Conclusions

We cannot say with certainty what health hazards are caused by fallout from nuclear testing. We expect there will be some genetic effects; other effects such as leukemia and cancer are more speculative and may not occur at all. We can observe that, compared to the number of these same adverse biological effects occurring wholly apart from testing, the additional cases that might be caused by testing are a very small quantity. We conclude that nuclear testing through 1961 has increased by small amounts the normal risks of adverse health effects.

APPENDIX "A"

EXPLANATORY MATERIAL ON DOSE ESTIMATIONS

The estimates of radiation doses attributable to fallout from tests of nuclear weapons given in Table I have been based on extensive observations and studies through 1961. These estimates include exposures from fallout which already has occurred and from material from past tests yet to be deposited. Estimates are based on measurements of radionuclides in air, rain, soil, water supplies, food, and people.

Table I gives estimates of radiation doses from fallout resulting from tests through 1961. The dose ranges given in this table represent estimates made using somewhat different but plausible assumptions concerning such factors as fallout distribution, the effects of weathering and shielding, and the movement of radioisotopes from the environment to man. It is believed that the best estimates that can be made at the present time would lie within the ranges given.

In the cases of whole body and reproductive cell exposures, radiation doses are relatively independent of age, except for the fact that children born in the past two or three years will have missed much of the exposure from earlier tests experienced by older persons. A large fraction of the dose to the whole-body and reproductive cells from a particular test may be received within a period of months after fallout occurs. The contribution of radioiodine to the dose to the thyroid gland is much larger in the case of infants than in older persons and is effectively complete within a few weeks after a nuclear test.

Radiation doses to the bone and bone-marrow from a particular test will be received at decreasing rates over a period of a lifetime. Early concentrations in the bone will be greatest for those children who are less than one year of age at the time that peak concentrations of fallout occur in food. The average bone and bone marrow doses to such children as estimated in Table I are much larger than the average to the whole population.

It is estimated that carbon-14 resulting from tests through 1961 will produce a radiation dose to the whole body including the reproductive cells of 10 to 15 millirems in the first 30 years, which is less than one percent of the 30 year genetic dose to the present population from natural background.

While carbon-14 decays very slowly with a radioactive half-life of 5,700 years, its availability as a source of radiation exposure initially decreases rather rapidly because of absorption of carbon dioxide from the atmosphere into the oceans. In a period of one or two hundred years, the exchange between the atmosphere and the ocean approaches an equilibrium with most of the carbon-14 in the oceans. This mixing will reduce the carbon-14 due to weapons tests to about two percent of the natural carbon-14 concentration in the atmosphere, biosphere and oceans. The radiation dose rate at this time will be about 0.025 millirem per year, or 0.75 millirem per generation. Although the dose rate is very small, it will continue at a rate which decreases with the radioactive decay of carbon-14 through hundreds of generations.

Doses to the whole-body and reproductive cells were averaged, weighted according to population; bone and thyroid doses were averaged over that portion of the population who were infants at the time of highest concentrations of relevant radioisotopes in the diet. Average doses to older children and adults, and thus to the total population, were smaller. Some local averages, particularly in the case of the thyroid, were much higher.

All one year doses are for the year, within the period covered, in which the highest yearly doses were received. The highest one-year doses to the whole-body and skeleton from tests prior to 1961 were experienced in 1958-1959. The highest one-year doses to the whole-body and to the skeleton from the 1961 tests are expected during 1962 and 1963.

TABLE I

Estimated Radiation Doses in the United States

(Doses expressed in millirem)

Tissue or organ	From all tests through 1961	From natural background	FRC Radiation Protection Guides* for normal peacetime operations Population groups
Whole body			
1 Year	10- 25	100	170
30 Years	60-130	3,000	5,000
70 Years	70-150	7,000	11,900
Reproductive cells			
1 Year	10- 25	100	170
30 Years	60-130	3,000	5,000
70 Years	70-150	7,000	11,900
Bone			
1 Year	30- 80	130	500
70 Years	400-900	9,100	35,000
Bone marrow			
1 Year	20- 40	100	170
70 Years	150-350	7,000	11,900

*The Radiation Protection Guide for whole-body exposure of individual radiation workers is 5,000 millirems per year.

APPENDIX "B"

DISCUSSION OF THE NUMERICAL VALUES IN TABLES II AND III

The estimates of genetic effect are based largely on the reports of the Committee on Genetic Effects of the National Academy of Sciences, contained in the Academy's 1956 and 1960 Summary Reports on the Biological Effects of Atomic Radiation. The Summary Reports concluded from the available scientific information that the genetic effects of exposure of a population to small doses of radiation are proportional to the average dose to the reproductive cells of potential parents.

The Committee reported that normally some four to five percent of children born have or will develop a severe physical or mental defect. Of these defective children about half, or two percent of the total number born, are thought to have traits whose frequency in the population is directly dependent on the mutation rate.

The Academy Committee utilized data on mutation rates in mice and estimated the effects on human populations, assuming that human radiation-induced mutation rates are the same as in mice. The 1956 Report estimated that if the parents of the present generation were exposed to 10,000 millirems, this average dose would give rise to some 50,000 additional defective children among 100 million children born. The total number for all future generations, assuming no change in the size of population, was estimated as 500,000.

Recent data have shown that radiation given at a very low rate produces fewer mutations than the same total dose given quickly. Since the earlier estimates were based on high dose rates, they should be reduced accordingly. The results from recent experiments with mice indicate that when both parents are irradiated the best estimate of the number of mutations should be only 1/6 as large as with high dose rates.

An application of these modified estimates to the reproductive cell exposures estimated to occur from past weapons tests, approximately 100 millirems over the first 30 years, leads to an estimate of 110 cases of serious inherited defects in the first generation of 130 million births. The estimates of radiation doses in Table I apply only to radiation received by the present population of the United States.

At least four physical phenomena contribute to making the radiation doses to future generations from these tests much smaller. In fact, in a few decades the exposure per generation from residual radioactivity produced by these tests will have dropped to less than one percent of the exposure to the current population.

In the case of the whole-body and reproductive cells, about 50% of the 30-year dose from tests through 1961 has resulted from exposure to radiation from relatively short-live gamma-emitting materials outside the body. As a result of radioactive decay, these will have essentially disappeared within a few years.

It is estimated that about 20 percent of the 30-year dose is from cesium-137 in the diet. Most of this results from the direct deposition of fallout on vegetation. When the deposition rate is low, the availablility of cesium-137 is small. This factor, together with its short retention time in the body, makes this radioisotope a small contributor to internal irradiation. About 25 percent of the 30 year dose is due to cesium-137 outside the body. The dose rate from this source decreases with time, not only as a result of radioactive decay with a half-life of 27 years, but also because of decreasing availability due to migration into the earth or into streams, storm drains, etc. The dose rate from this isotope may be reduced by 1/2 to 1/10 after 30 years in addition to radioactive decay.

It is estimated that carbon-14 resulting from tests through 1961 will produce a radiation dose of 10 to 15 millirems in the first 30 years, about 10 percent of the 30 year genetic dose from fallout to the present population. The radiation dose rate, after equilibrium with the oceans has been reached, will be about 0.025 millirem per year, or 0.75 millirem per generation. Although the dose rate is very small, it is of interest because it will continue at a rate which decreases with the radioactive decay of carbon-14 through hundreds of generations.

In addition to its radiation effects, carbon-14 may produce mutations through disruption of the normal chemical structure of the gene when the atom of carbon-14 is converted into nitrogen. The contribution from this effect appears to be small in comparison to the radiation effect, and is too speculative to provide a firm basis for numerical estimates.

The current total incidence of deaths due to leukemia in the United States is about 12,000 per year and that of bone cancer is about 2,000 per year. These amount to average rates for all ages of 7 cases per one-hundred thousand persons and 1.1 cases per one-hundred thousand persons, respectively.

It is assumed that the incidence of these diseases as a result of exposure of the blood-forming tissues and the bone, respectively, to radiation is proportional to the exposure. Observations of number of cases of leukemia resulting from very large doses of radiation suggest that up to ten percent of the normal incidence of leukemia may be due to exposure to radiation from natural sources, amounting to an average of 7,000 millirems in 70 years. The same assumption has sometimes been made for bone cancer. These assumptions were made, for example, by the United Nations Scientific Committee on the Effects of Atomic Radiation (1958) in estimating an upper limit to the number of cases of leukemia and bone cancer that might be expected from low levels of exposure such as those from fallout from the testing of nuclear weapons.

On this basis, one could estimate that if an average lifetime exposure of 7,000 millirems to the blood-forming tissues of the population of the United States results in a total of about 84,000 cases of leukemia in the period of an average lifespan of 70 years, the average lifetime exposure to fallout could be expected to result in a total of up to 2,000 cases of leukemia, averaging about 30 per year. The average exposure to the population as a whole from fallout is estimated to be about 175 millirems to the bone marrow, about half the value calculated for infants, as shown in Table I. A corresponding estimate for the number of cases of bone cancer from a population weighted lifetime dose of about 450 millirems would give an upper limit of 700 cases in 70 years, averaging about 10 cases per year.

For comparison, there are about 1,700,000 deaths each year in the United States from all causes. Of these, up to about 1,400, or about 10% of the total due to leukemia and bone cancer from all causes, are attributed to radiation exposure from natural sources. The possible additional 40 deaths from these causes, as estimated above, illustrate the degree of risk to an individual from fallout in comparison to risks already present.

TABLE II

Effect of Fallout on the Number of Gross Physical or Mental Defects in Future Generations in the United States

(No allowance has been made for future increases in population)

(1) Estimated number of cases due to all causes (hereditary and non-hereditary) in children of persons now living	(2) Estimated number of additional cases in the first generation (children of persons now alive) caused by all tests through 1961		(3) Estimated total number for all future generations from all tests through 1961		(4) Risk to an individual of the next generation from all tests through 1961
	Fallout	Carbon-14	Fallout	Carbon-14	
4,000,000-6,000,000	100 Range (20-500)	10 (2-50)	1,000 (200-5,000)	2,000 (400-10,000)	1/1,000,000

The upper figures in columns 2 and 3 are best estimates based on radiation-induced mutation rates in mice, and on the spontaneous incidence of these defects in man.

The lower sets of figures represent the range within which the true value may reasonably be expected to lie.

TABLE III

Certain Malignant Diseases in the Next Seventy Years in the United States

	Estimated total number of cases from all causes (present incidence)	Estimated number of cases caused by natural radiation	Estimated number of additional cases from all tests through 1961	Risk to an individual of developing the disease due to all tests through 1961
Leukemia............................	840,000	0-84,000	0-2,000	0-1/100,000
Bone Cancer	140,000	0-14,000	0-700	0-1/300,000

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ESTIMATES AND EVALUATION OF FALLOUT IN THE UNITED STATES FROM NUCLEAR WEAPONS TESTING CONDUCTED THROUGH 1962

MAY 1963

REPORT OF THE

FEDERAL RADIATION COUNCIL

REPORT NO. 4

ESTIMATES AND EVALUATION OF FALLOUT IN THE UNITED STATES FROM NUCLEAR WEAPONS TESTING CONDUCTED THROUGH 1962

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SUMMARY

As a sequel to a similar report last spring, the Federal Radiation Council has again made a full study and analysis of fallout expected in the current year from nuclear tests in the past. In this case the report covers fallout expected in the next few years from Soviet and United States tests conducted to date.

Although absolute fallout levels in the U.S. in 1963 will probably be substantially increased over 1962 if rainfall is normal, they will still be, in relative terms far short of figures which would cause concern or justify counter-measures. Cumulative whole-body radiation doses from all past tests is estimated to be 110 millirems in 30 years, which is about one-thirtieth the exposure from natural sources such as soil, rocks, and building materials. The special cases of iodine-131 and strontium-90, the two radionuclides of most concern to the public, have been thoroughly reviewed and specifically included in the general conclusion. The Council concludes that the health risks from radioactivity in foods, now and over the next several years, are too small to justify countermeasures to limit intake of radionuclides by diet modifications or altering the normal distribution and use of food, particularly milk and dairy products.

The substantial increase in absolute amounts of fallout is due primarily to Soviet nuclear tests. The amount of fission yield in the thermonuclear test explosions is a measure of the quantity of strontium-90 and other fission products produced by the tests. The total yield of thermonuclear explosions is a measure of the carbon-14 produced. Since the Soviet Union ended the three-year moratorium by resuming nuclear tests in 1961, Soivet testing has produced 85 megatons of fission yield, and U.S. testing 16 megatons.

This report updates weapons testing information to include all tests conducted through 1962. The USSR conducted atmospheric tests at levels of 120 megatons (MT) total yield and 25 MT fission yield in 1961; 180 MT total yield and 60 MT fission yield in 1962. A few of the underground tests conducted by the U.S. in 1961 resulted in some venting to the atmosphere. The U.S. conducted a series of atmospheric tests in the Pacific at a level of 37 MT total yield and 16 MT fission yield in 1962 plus a few low yield tests at the Nevada Test Site.

Measurements of strontium-90 in food supplies and the total diet in the U.S. show that the levels rose from a value of 4-8 strontium units (SU) in 1961 to 8-13 SU in 1962, and may rise to a peak value of 50 SU in 1963. The predicted concentrations of strontium-90 in milk for 1963 are twice the values observed in 1962 and about 4 times the values observed in 1961. The strontium-90 concentrations in human bone are expected to rise from an observed value of 2.6 SU in 1961 to 7 SU in 1964. The presently estimated radiation dose to bone from all past tests is about 465 millirems in 70 years, which is about one-twentieth the exposure from natural sources. It should be noted that these presently predicted values are no greater than those which were predicted in the FRC Report No. 3 as likely to result from all tests conducted prior to 1962. This is because the measured levels are lower than originally predicted.

It was estimated in 1962 that carbon-14 resulting from tests conducted through 1961 would give an average per capita radiation dose to the whole-body including the reproductive cells of 10 to 15 millirems in the first 30 years. It is now estimated that the carbon-14 produced by testing conducted in 1962 will produce a comparable radiation dose in the first 30 years. When the carbon-14 now in the atmosphere has equilibrated with the oceans, the natural levels will be increased by about 4 percent instead of the 2 percent previously reported.

As an addition, FRC Report No. 3, "Health Implications of Fallout from Nuclear Weapons Testing through 1961," is attached for reference.

SECTION I

INTRODUCTION

1.1 The Federal Radiation Council evaluated the health implications of fallout from nuclear weapons testing conducted through 1961 in its Report No. 3 issued in May 1962. Since that report was prepared, additional atmospheric testing of nuclear weapons has been conducted by the USSR and U.S. governments. The purpose of the present report is to:

a) Update the information concerning the scale of weapons testing programs conducted by all nations;

b) Summarize the radiation doses experienced in the past and expected in the future;

c) Evaluate the change in the inventories of long-lived radionuclides in the stratosphere and on the ground resulting from these tests;

d) Predict the probable levels of fallout that may be expected in 1963 and subsequent years in the food supplies of the nation; and

e) Draw conclusions about the suitability of food products for human consumption in view of the predicted levels of radionuclides.

1.2 The predictions of future fallout levels from testing conducted through 1962 are based on the information available through March 1963. The estimates of doses received in 1962 are based on extensive measurements of the radionuclide concentrations in air, rain, soil water supplies, food supplies, and people.

SECTION II

HISTORY OF NUCLEAR WEAPONS TESTING

2.1 The atmospheric testing of nuclear devices inevitably introduces radioactive nuclides into man's environment. The existence of many of these products is transitory due to the process of radioactive decay. Other species, notably carbon-14, are so long-lived that they can be considered as a permanent man-made modification of the environment. Historically, major attention has been focused on the production and distribution of strontium-90 and cesium-137, both of which can lead to radiation exposure over the full lifetime of persons now living. Of the shorter-lived radionuclides, iodine-131 has been emphasized.

2.2 The production of strontium-90 and other fission products depends on the fission yields of the devices. The production of carbon-14 depends on the total fission plus fusion yields of the devices.

2.3 Table 1 summarizes the fission and total yields of atmospheric testing conducted by all nations through December 1962. As of January 1959, the strontium-90 inventory was estimated to be 9.2 megacuries produced by the detonation of 92 megatons of fission yield, 40 megatons of which had been detonated in 1957 and 1958 1/. Of this inventory, it was estimated that 3 megacuries had deposited as "close in" fallout near the test sites. Of the 6 megacuries then available for worldwide deposition, 3 megacuries had been deposited as worldwide deposition, and 3 megacuries were still in the atmosphere. The available inventory as of May 1961, taking into account the decrease of 2.5 percent per year for the radioactive decay of strontium-90, was estimated as 5.2 to 5.3 megacuries strontium-90. Of that quantity, 4.2 megacuries had deposited on the ground and 1 megacurie was still in the atmosphere. Less than one-quarter of this atmospheric burden was in the lower stratosphere in the northern hemisphere.

2.4 The USSR detonated an estimated 120 megatons of total yield in 1961 of which about 25 megatons were due to fission yield. The estimated radiation doses from this series were presented in FRC Report No. 3, "Health Implications of Fallout from Nuclear Weapons Testing through 1961."

2.5 The United States and the Soviet Union conducted tests in 1962 at levels shown in Table 2. U.S. and Soviet tests do not contribute equally to fallout exposures in the U.S. not only because of the difference in fission yields, but also because the distribution and rate of deposition vary with the geographic location of the tests and the altitude to which the weapon debris is carried. The amounts of fission yield injected into the stratosphere by the U.S. and the USSR in 1961 and 1962 are shown in Table 3. The total of 57 megatons fission yield injected into the lower stratosphere in 1961 and 1962 dominates the inventory available for worldwide deposition in 1962, and in the next few years.

1/ 10 megatons of fission yield produce approximately 1 megacurie of strontium-90.

TABLE 1

Approximate Fission and Total Yields of Nuclear Weapons Tests Conducted in the Atmosphere by All Nations

(Yield in Megatons)

Inclusive Years	Fission Yield Air	Fission Yield Surface	Total Yield Air	Total Yield Surface
1945 - 1951	.19	.52	.19	.57
1952 - 1954	1	37	1	59
1955 - 1956	5.6	7.5	11	17
1957 - 1958	31	9	57	28
Subtotal	37.8	54	69.2	104.6
1959 - 1960	TEST		MORATORIUM	
1961	25 1/		120	
Subtotal	63	54	189	105
1962	76 1/		217	
TOTAL	139	54	406	105

1/ The small yield tests conducted in Nevada do not contribute significantly to the worldwide distribution of strontium-90 to which this summary is related

TABLE 2

Approximate Fission and Total Yields of Atmospheric Tests Conducted in 1962

(Yield in Megatons)

	Fission Yield	Total Yield
U.S.	16	37
USSR	60	180
TOTAL	76	217

TABLE 3

Approximate Fission Yields Injected into the Stratosphere in 1961 and 1962

(Yield in Megatons)

	Lower Stratosphere 1/ (MT)	Upper Stratosphere 1/ (MT)	Total (MT)
USSR (1961)	17	8	25
USSR (1962)	30	30	60
U.S. (1962)	10	1	11

1/ The lower stratosphere occupies the first few tens of thousands of feet above the tropopause and the upper stratosphere continues to about 150,000 feet. The tropopause, on the average, is located at 30 - 40,000 feet in the temperate and polar zones and 50 - 55,000 feet in the tropical and the equatorial zones. Debris injected above 150,000 feet is omitted from this table.

SECTION III

ATMOSPHERIC TRANSPORT AND DISTRIBUTION OF FALLOUT

3.1 The future course of fission-product deposition in man's environment resulting from past nuclear detonations can be estimated either from a knowledge of the amount and distribution of these products in the atmosphere at some recent date or from an estimate of the time, place, and amount injected into the atmosphere by the various test series. These data can be utilized in conjunction with the experience and knowledge gained over the past decade in analyzing fallout phenomenology. Studies of the movement and deposition of debris from past test series, using short-lived isotopes and unique radioactive tracers to identify the sources of the debris, have added to our understanding of the role of the atmosphere in determining the ultimate distribution of fission products on the surface of the earth.

3.2 Although the exact mechanisms involved in the transfer of debris from the stratosphere to the surface of the earth are not completely understood, the general features of the distribution on the ground are known from the available fallout data. These data show that precipitation is the most important mechanism in depositing material on the surface, and that there are both a latitudinal variation, with most deposition in temperate latitudes, and a seasonal variation with maximum deposition in the spring.

3.3 On January 1, 1963, the accumulated levels of strontium-90 deposited over the United States varied from about 100 to 125 millicuries per square mile in the "wet" areas (areas of greatest annual precipitation) to 40 to 50 millicuries per square mile in the "dry" regions. Figure 1 shows the continental United States; the areas considered as "wet" are closely hatched, "dry" areas are unshaded, and intermediate precipitation regions have widely spaced hatching.

3.4 Utilizing sampling data obtained by the Defense Atomic Support Agency's STARDUST Program, it is possible to compare the burden of strontium-90 in the lower stratosphere in early 1963 with the burden approximately a year earlier. Experience indicates that debris present in January up to 55,000 feet will appear in the fallout of the coming year. Figure 2 shows the strontium-90 concentration up to 70,000 feet, the ceiling of the sampling aircraft, in early 1963. The stratosphere below 55,000 feet in the northern hemisphere contained about 2 megacuries of strontium-90 in early 1963, while about 1 megacurie was observed in the same region in early 1962. Thus, the 1963 fallout is expected to be about twice that of the stratospheric component in 1962, as shown in Table 4. About 80 percent of the stratospheric burden available for fallout in 1963 came from testing conducted in 1962. The apparent age of the 1963 spring fallout is expected to correspond to a mean production time of mid-September 1962. An independent analysis of the input of strontium-90 based on the fission yields given in Table 3 agrees with the estimates in Table 4.

3.5 In Table 4 the annual fallout estimates from weapons tests already conducted have been extended, with considerable uncertainty, to future years. Since the half-life of strontium-90 is 28 years, it decays at the rate of 2.5 percent per year. By 1966, radioactive decay of the accumulated strontium-90 should exceed deposition, resulting in a gradual lowering of the strontium-90 values in succeeding years.

3.6 The possibility exists that fallout estimates can be in error by a factor of two for the year 1963 and by more than a factor of two in subsequent years. The uncertainties in the estimates of fallout are largely due to data limitations, incomplete understanding of atmospheric behavior, and year to year weather differences.

FIGURES

Fig. 1 Schematic representation of "wet" and "dry" areas in the continental United States.

Fig. 2 Mean distribution of strontium-90 (Disintegrations per minute per 1000 standard cubic feet of air) observed by the STARDUST Program December 1962 through January 1963. (Preliminary).

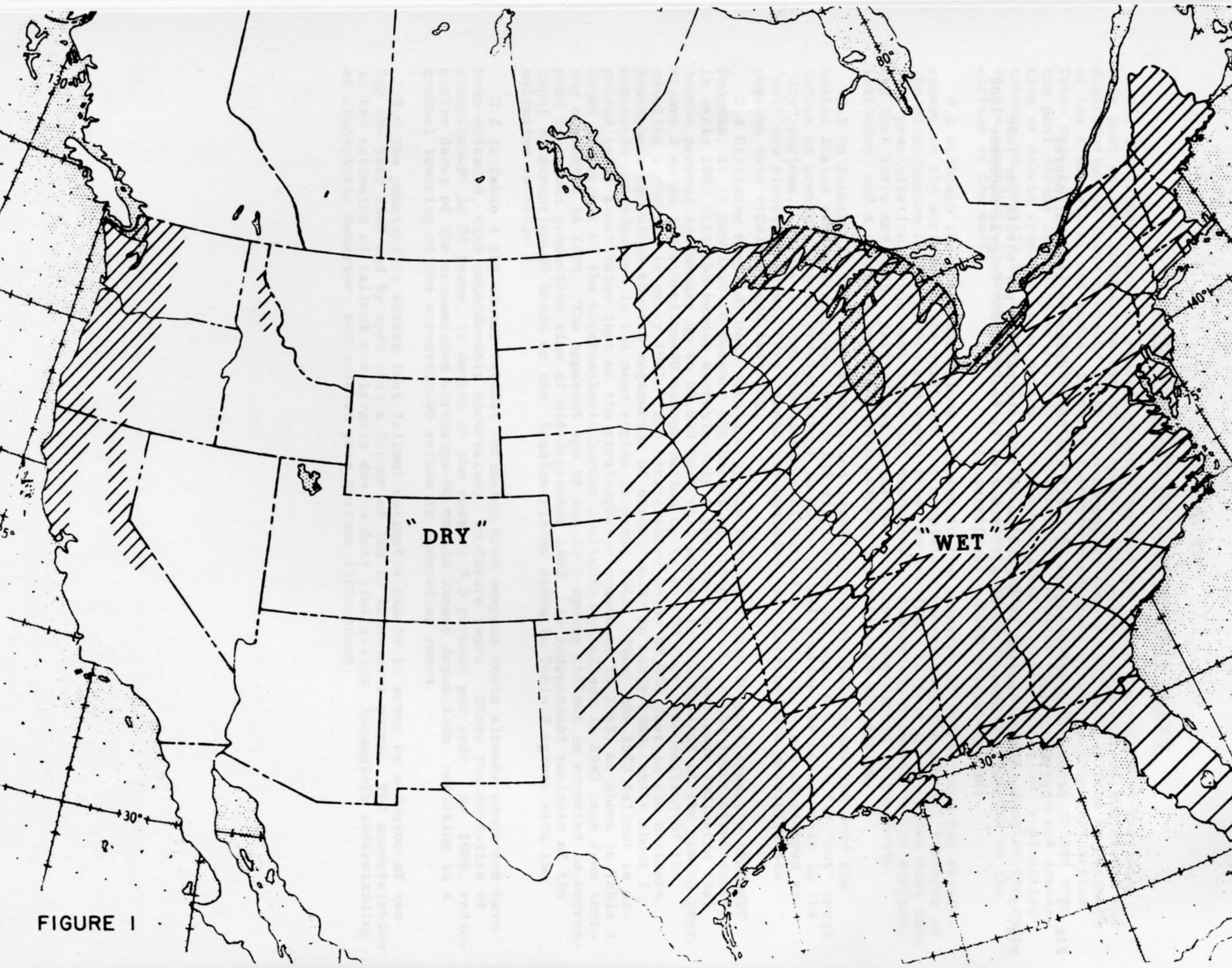

FIGURE I

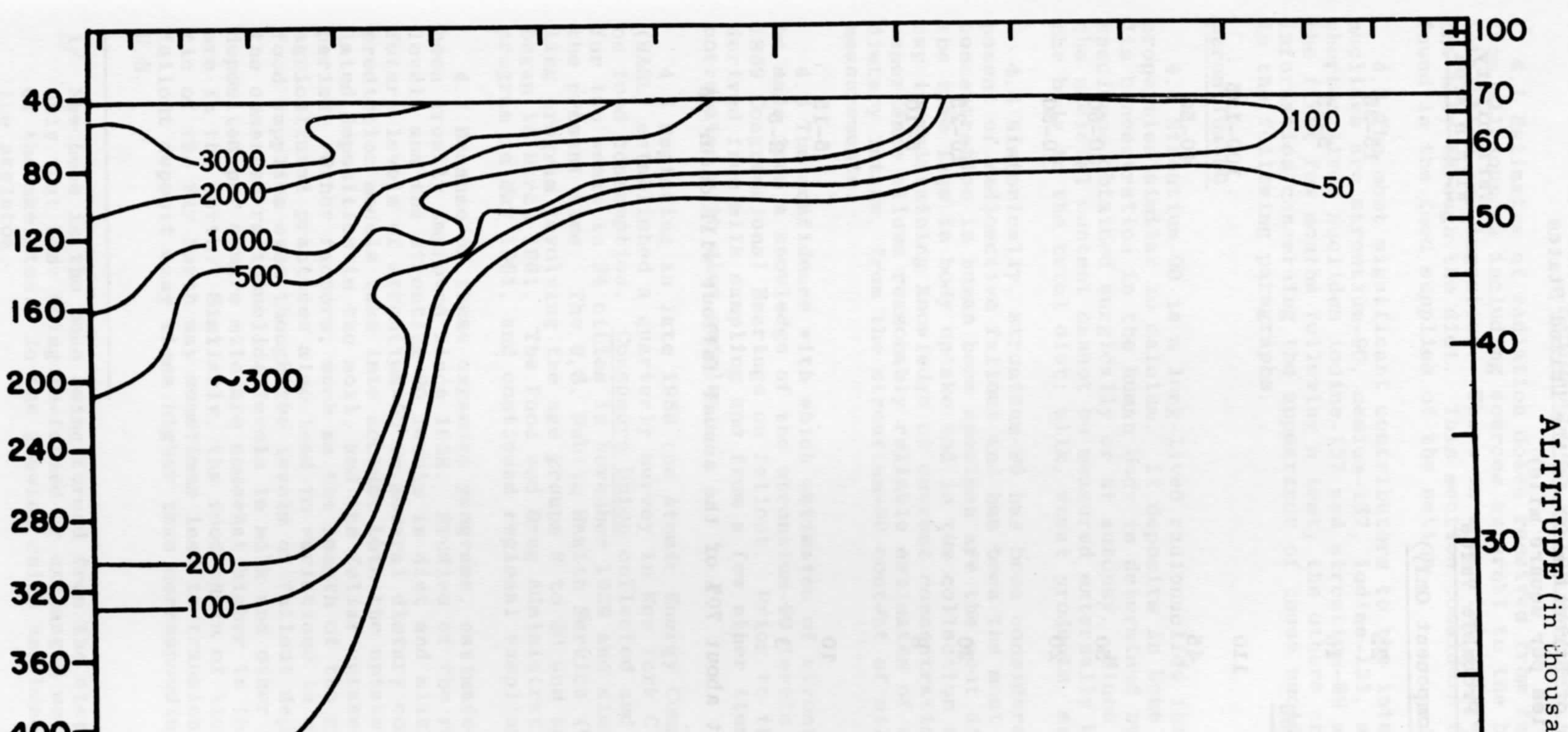

FIGURE 2 MEAN DISTRIBUTION OF STRONTIUM-90 OBSERVED BY THE STARDUST PROGRAM

TABLE 4

Expected Annual Deposition of Strontium-90 in the United States
(millicuries per square mile)

	Most Probable Value	Variability Within Area
Deposition During 1962 (Stratospheric Component Only)		
"Wet" area	25	15-35
"Dry" area	10	5-15
Accumulated Deposition to January 1, 1963		
"Wet" area	110	100-125
"Dry" area	45	40-50
Expected Deposition During 1963		
"Wet" area	50	30-60
"Dry" area	20	10-30
Expected Deposition During 1964		
"Wet" area	20	10-25
"Dry" area	8	5-10
Expected Deposition During 1965		
"Wet" area	10	5-15
"Dry" area	3	2-5

NOTE: In each year, it is expected that about 70% of the annual fallout will occur in the first six months of the year.

SECTION IV

RADIONUCLIDES IN THE DIET AND IN PEOPLE

4.1 Estimates of radiation doses received from fallout must take into account exposures from all sources including sources external to the body and those which enter the body by inhalation and ingestion. There is a special interest in those radionuclides that enter the body through the diet. This section considers that part of fallout debris which is found in the food supplies of the nation.

4.2 The most significant contributors to the internal dose to man from fallout radionuclides are strontium-90, cesium-137, iodine-131, strontium-89, and carbon-14. The shorter lived nuclides iodine-131 and strontium-89 are significant in fallout only over the first few months following a test; the others are of importance over many years. Information concerning the appearance of these nuclides in the diet and in man is provided in the following paragraphs.

Strontium-90

4.3 Strontium-90 is a long-lived radionuclide (half-life of 28 years) with chemical properties similar to calcium. It deposits in bone where it has a long residence time. Its concentration in the human body is determined by radiochemical analyses of bone specimens obtained surgically or at autopsy. Since strontium-90 emits only beta particles, the skeletal content cannot be measured externally by instrumental methods. It enters the body in the total diet; milk, wheat products, and vegetables are the main contributors.

4.4 Historically, strontium-90 has been considered the most potentially hazardous component of radioactive fallout and has been the most widely studied. Measurements of its concentration in human bone specimen are the most direct approach to dose estimation, but the time lags in body uptake and in the collection and analyses of specimens are a handicap in maintaining knowledge of current concentrations in the skeleton. However, past experience allows reasonably reliable estimates of strontium-90 in new bone 1/ from total dietary intake, from the strontium-90 content of milk, or from fallout deposition measurements.

4.5 The confidence with which estimates of strontium-90 concentrations in new bone can be made from a knowledge of the strontium-90 levels in the diet has increased since the 1959 Congressional Hearings on fallout. Prior to that time, diet information was largely derived from milk sampling and from a few other items, but the bone sampling was not correlated with diet samples.

4.6 Beginning in late 1959 the Atomic Energy Commission's Health and Safety Laboratory (HASL) established a quarterly survey in New York City, San Francisco, and Chicago based on food consumption. Consumers Union collected and analyzed complete diets of teen-agers for two weeks in 24 cities in November 1959 and similar collections have been made up to the present time. The U.S. Public Health Service (USPHS) monthly institutional diet sampling program involving the age groups 8 to 20 and now covering institutions in 22 states began in March 1961. The Food and Drug Administration (FDA) set up a total diet sampling program in May 1961, and continued regional sampling of major food items.

4.7 Because of these expanded programs, estimates of dietary strontium-90 levels have been greatly improved since 1958. Studies of the relationships between fallout deposition levels and the strontium-90 levels in diet and milk have provided a basis for predicting future levels of strontium-90 in several dietary components and in total intake. These prediction models take into account both the uptake by plant roots from the total accumulated deposition in the soil, and the foliar uptake of fallout deposited during the growth period. Other factors, such as the length of the growing season and differences in agricultural practices also lead to variations in radionuclide concentrations in man's food supplies even though the levels of fallout deposition appear to be similar. Thus, the observed radionuclide levels in milk and other foods per millicurie of strontium-90 deposited per square mile are somewhat higher in the southern part of the U.S., than they are in the north. Similarly, the food chain of lichen-caribou-man, which is characteristic of the Far North may sometimes lead to transient levels in food for a given level of fallout deposit many times higher than corresponding levels in the "wet" areas of the U.S.

1/ New bone is the bone being formed from the dietary components. In the adult it is only that bone being re-formed or exchanged metabolically, and is a small fraction of the skeleton. In the growing child new bone represents a much higher portion of the skeleton.

4.8 Studies of strontium and calcium metabolism show that the ratio of strontium-90 to calcium in new bone may be estimated as about one-fourth of the ratio in the diet, since the body uses calcium preferentially over strontium. This metabolic discrimination against strontium may be less in infants, but the strontium-90/calcium ratio in new bone will not be greater than that of the diet.

4.9 Based on these considerations and on fallout predictions for 1963, 1964, and 1965, as as described in Section III, predictions of strontium-90 levels in total diet, diet components, and bone have been made.

Total Diet

4.10 Table 5 shows the strontium-90/calcium ratios in the U.S. total diet obtained by measurements made from 1959 through March 1963, and values predicted in the future for the total diet in the "wet" and "dry" areas of the U.S. Following the peaks of 13 to 18 SU (Strontium Unit-See Glossary) reached in 1959 as a result of 1958 weapons tests, the levels dropped by 1961 to 4 to 8 SU. The rise at the end of 1962 and early 1963 resulting from tests in 1961 and 1962 will continue to a predicted maximum of 50 SU in 1963.

4.11 These predicted values resulting from tests conducted through 1962 can be compared with measurements made since 1959 only on the basis of average levels for broad regions. Measurements made in the pasteurized milk network during 1961 and 1962 indicate that the average annual concentration of strontium-90 in milk produced in the "wet" area of the U.S. is about 1.5 times greater than the annual average for milk produced in the "dry" area. The maximum difference between the lowest station in the "dry" area and the highest station in the "wet" area in 1962 was about a factor of 10 for the radionuclides of interest. The average annual intake of radionuclides in some regions may be about 3 times higher or 3 times lower than the overall national average. 1/ The data from Table 5 show that the annual intake of strontium-90 in a diet representative of a typical person in the U.S. dropped from about 15 SU in 1959 to a low of about 6 SU in 1961 before the resumption of nuclear testing. The large increase predicted for the year 1963 was not generally evident in measurements made through March. However, the maximum fallout rates are expected to have occurred during the months of April and May, so surveillance measurements of nuclides such as cesium-137 and strontium-89 should show sharp increases by June if these predictions are approximately correct. The decrease in subsequent years reflects the diminished fallout rates predicted for those years.

Diet Components

4.12 The percentage contributions of four major diet categories to the diet weight strontium-90 and calcium intakes for the tri-city diet studies of the Health Safety Laboratory are shown in Table 6. It is apparent that an attempt to substitute other diet items for milk would decrease calcium intake more sharply than strontium-90 and in fact increase the strontium-90/calcium ratio of the diet. A number of studies have shown that conservative estimates of the strontium-90/calcium ratio in the total diet may be made by multiplying the ratio of strontium-90/calcium in milk for a particular locality by 1.5. The strontium-90/calcium ratio in milk may be the same as that in the diet during periods of fresh fallout.

4.13 The levels of strontium-90 in milk measured in the past, and predicted for the future are shown in Table 7. The measured values of strontium-90 in the milk supply of New York City were about 9 picocuries per liter of milk in 1959 and dropped to a low of 8 picocuries in 1961. The concentration rose to a value of about 14 picocuries per liter of milk in 1962 and is projected to average about 30 picocuries per liter in 1963 and then drop to values of about 17 picocuries per liter by 1965. It should be recognized that Table 5 considers the total diet which contains food from several areas, while Table 7 is concerned with milk alone. The relationship that the strontium units in the total diet equal 1.5 times the strontium units in milk was derived when this relationship was stable. The predictions in Table 5 cannot be derived from Table 7 since, as already noted, the relationship changes during periods of fresh fallout.

4.14 The levels of strontium-90 in wheat and in white flour measured in the past and predicted for the future are shown in Table 8. Wheat levels are more dependent on the fallout rate component than are milk levels and thus they vary over a wider range.

1/ This information is of interest since previous estimates have presented the analyses in terms of the national average, whereas an attempt is being made to analyze the "wet" and "dry" regions separately in this report.

4.15 The levels of strontium-90 in wheat are among the highest found in important food items. The maximum level resulting from past weapons testing is expected in the 1963 wheat crop and may average as high as 250 picocuries of strontium-90/kilogram in harvested wheat. Milling, distribution, and storage practices bring about much lower levels in major dietary wheat products, and also make it unlikely that levels of strontium-90 ingestion through wheat products in any particular area will differ much from the national average.

4.16 From 70 to 80 percent of the wheat consumed by humans in the United States is in the form of bread made from white flour. This wheat is produced almost entirely on the Great Plains from Texas to North Dakota and Montana, and the concentration of strontium-90 has differed little from the national average in any past year. Most of the remaining wheat is consumed in the form of other baked goods and is produced primarily east of the Mississippi River or in the Pacific Northwest. Less than five percent of the wheat consumed is in the form of whole wheat bread or cereals, and very little is in the form of bran. Although the latter products contain a higher concentration of strontium-90 than white flour or whole wheat, the relatively small quantities consumed prevent them from becoming major contributors of strontium-90 in the total diet.

4.17 Water, meat, fish, poultry, eggs, sugars and fats contribute negligible amounts of strontium-90 to the diet. Fruits and vegetables contribute about one-third of the total intake of strontium-90, which is quite comparable with their weight intake. These figures are based on the foods as prepared for eating; slightly higher values are found in the raw unwashed items.

4.18 The levels of strontium-90 measured in the past and predicted for new bone in the future are shown in Table 9. The predicted value for new bone is taken as one-fourth the predicted strontium-90/calcium ratio in the total diet in order to indicate the concentrations being deposited in the skeletons of the younger age groups. However, as pointed out in FRC Report No. 2, the mean bone dose is a better estimate of risk inasmuch as a larger volume of tissue is affected. Calcium and strontium-90 in new bone is continually redistributed as the result of normal bone metabolism, so the observed values in the skeleton would be expected to be lower than the maximum concentration in new bone during a relatively short period of time (i.e., one year). Thus the calculated concentrations of strontium-90 in new bone in 1963, 1964, and 1965 are 12, 8, and 5 SU respectively, whereas the values estimated in bone for the 0-4 age group are about 5, 7, and 7 SU respectively in the "wet" areas of the United States and 3, 5, and 5 SU respectively in the "dry" areas.

Cesium-137

4.19 Cesium-137, another long-lived radionuclide (half-life 30 years), distributes itself throughout soft tissue and has a relatively short residence time in the body. Its gamma radiation allows direct measurement in the living body with a whole-body counter.

4.20 The distribution of cesium-137 in the diet is not well defined, but milk, meat, and vegetables are the main contributors. Trends in dietary cesium-137 have been similar to those for strontium-90, in that both tend to fluctuate with fallout rate. Because of this dependence on fallout rate and the rapid turnover rate of cesium in the body, cesium-137 levels in foods and in the body increase and decrease more rapidly than levels of strontium-90. Peak concentrations of cesium-137 in milk have appeared about one month after peak fallout rates, and peaks in the balance of the diet have appeared about one year after peak fallout rates. Peak levels in people have been observed about seven months after peaks in fallout rates.

4.21 Because of the differences in the mechanisms by which cesium-137 moves through the environment, predictions for cesium-137 cannot be made on the same basis as those for strontium-90. About all that can be done is to make comparisons with previous test patterns and the corresponding observations for milk and man, and noting that a year by year comparison is not direct inasmuch as there are different time lags in the responses. Table 10 gives the observations on cesium-137 measured in pasturized milk samples by the U.S. Public Health Service from 1959 through the first quarter of 1963. Table 11 gives measured and predicted concentrations of cesium-137 in milk and man.

4.22 Table 10 shows that the concentration of cesium-137 in milk in picocuries per liter, was about 4 to 5 times the corresponding strontium-90 concentration in 1959; it was essentially the same as strontium-90 in 1960 and 1961; it rose to 3 to 4 times the strontium-90 concentration in 1962 as the result of fresh fallout in that year. Although there is no uniform relationship between cesium-137 and strontium-90 concentrations in milk, estimates based on fallout rate lead to the conclusion that the average "wet" area concentrations of cesium-137 in milk may be about 140, 70, and 30 picocuries per liter respectively in 1963, 1964, and 1965. The anticipated concentration in man is expected to be about 150 picocuries per gram of potassium 1/ in 1963 and then drop to a value below 100 by the end of 1965.

Iodine-131

4.23 Iodine-131 is a short-lived radionuclide (half-life 8 days) which concentrates in the thyroid gland. Its gamma radiation allows direct measurement in the body. The residence time in the body and the half-life are both short. Therefore iodine-131 disappears in a few weeks. The significant diet contributor is milk because the time lag between production, and distribution is only a few days.

4.24 The U.S. Public Health Service measurements of iodine-131 in milk are summarized in Table 10. Iodine-131 levels from past testing are based on values observed from 1959 through March 1963. Radioactive decay has reduced the iodine-131 resulting from tests conducted in 1962 to insignificant levels. The presentation of iodine-131 levels by "wet" and "dry" areas is included only to keep the form of the information comparable. The deposition of iodine-131 is largely associated with material initially injected into the troposphere and hence is not systematically related to the mean annual rainfall.

4.25 Since November 1961, the Public Health Service with the cooperation of selected medical centers throughout the continental United States has collected and analyzed several hundred thyroid autopsy specimens. The thyroids were primarily from adults experiencing a traumatic death. Iodine-131 values ranged from 0-20 picocuries per gram of thyroid with a probable mean in the range of 5-7 picocuries per gram. Iodine-131 in the thyroid was found only where appreciable levels of iodine-131 were observed in the pasteurized milk network samples in the area from which the thyroid specimen was obtained.

4.26 The highest station for iodine-131 in milk in the continental U.S. in 1962 was in Utah. A large percentage of the observed iodine-131 occurred as the result of atmospheric tests in Nevada. Although the Utah State Health Department reported iodine-131 concentrations in excess of 1000 picocuries iodine-131 per liter of milk for about a week, the equivalent daily intake for a year for the population in the milkshed would have been 103 picocuries iodine-131 per liter. Milk from individual farms or from individual cows could, of course, be higher or lower than the measured average for the station.

Strontium-89

4.27 Strontium-89 has a half-life of 50 days, and is similar chemically to strontium-90. It deposits preferentially in bone, and remains there until it is reduced to a negligible level through radioactive decay. Like strontium-90 it is a beta emitter and is measured in humans by the radiochemical analyses of bone samples obtained at autopsy. Milk is the important dietary contributor since time lags between deposition and the production and distribution of most other foods result in the radioactive decay of strontium-89. Strontium-89 appears in other foods attached to their surfaces.

4.28 The observed values for strontium-89 in milk since 1959 are given in Table 10. It can be seen that the annual average concentration for most stations was three to four times the corresponding concentration of strontium-90 for that station. Based on the apparent age of the fission debris in the stratosphere, the strontium-89/strontium-90 ratio in milk in 1963 may reach a maximum value of about 8 during the first part of the year, but due to the short half-life of strontium-89, the annual averages in 1963 should be comparable to those observed in 1962.

Carbon-14

4.29 Carbon-14 is a very long-lived radionuclide (half-life 5,760 years) produced by the interaction between neutrons and nitrogen in the atmosphere. It is produced naturally by cosmic radiation, and artificially by nuclear weapons. It follows non-radioactive carbon chemically and metabolically, and is part of all living matter. Carbon-14 in the body is essentially in equilibrium with carbon-14 in the environment. The environmental level tends to decrease slowly as carbon-14 enters the carbonates of the deep ocean waters and sediments. Carbon-14 emits only beta particles and cannot be measured directly in the body. All items of the diet contribute in proportion to their carbon content so that measurements made on atmospheric carbon dioxide, which is the source of plant carbon, can be substituted for measurements in the body.

1/ Potassium is essential to life and its naturally occurring radionuclide contributes a whole-body dose of about 20 millirems per year. It is chemically similar to cesium and is distributed through the soft tissues of the body. Therefore, cesium concentrations in people are usually reported as the cesium-137/potassium ratio.

4.30 As a result of nuclear weapons tests conducted through 1958 the tropospheric level of carbon-14 was about 30 percent above the equilibrium inventory of naturally produced carbon-14 in the atmosphere due to its normal production by cosmic radiation.

4.31 The testing conducted in 1961 and 1962 probably produced about 100 times more carbon-14 than was produced naturally by cosmic rays during the same period. This should raise the artificially produced carbon-14 in the atmosphere to twice the natural levels over the next several years. This excess carbon-14 is expected to be removed from the atmosphere by exchange with the ocean with a rate corresponding to a half-time (See Glossary) of about 33 years. Ultimately, about 96 percent will be removed, leaving an atmospheric level about 4 percent higher than the natural level. This conclusion is consistent with preliminary data from the stratospheric sampling program.

TABLE 5

Average Strontium-90 Content of U.S. Total Diet

($pc\ Sr^{90}/g\ Ca$)

	"Wet" Area	"Dry" Area
	Observed	
1959	13-18	9
1960	11	4
1961	4-8	3-6
1962	8-13	4-8
1963 (Through March)	10	8
	Predicted	
1963	50	35
1964	30	20
1965	20	10

TABLE 6

Average Percent Contributions of Diet Categories

	Diet Weight 1/	Diet Calcium	Approximate Percent of Annual Strontium-90 Intake: N.Y.	Chicago	S. F. 2/
Milk Products	33 6	61	51	39	37
Grain Products	14	15	16	26	24
Fruits and Vegetables	36	13	30	30	32
Others	17	11	3	5	7
	100	100	100	100	100

1/ The diet weights do not include water, coffee, tea and other nonmilk beverages.

2/ S.F. - San Francisco

TABLE 7

Average Strontium-90 Content in Milk in the U.S.

($pc\ Sr^{90}/l.$ of milk)

	New York	"Wet" Areas	San Francisco	"Dry" Areas
		Observed (PHS values)		
1959 1/	9	14	---	9
1960	9	9	4	5
1961	8	9	4	6
1962	14	15	5	10
1963 (1st Quarter)	16	18	8	11
		Predicted		
1963	31	-	11	-
1964	20	-	6	-
1965	17	-	4	-

1/ Based on raw milk data; dash (-) indicates no raw milk station.

TABLE 8

Strontium-90 Content of Wheat and Flour in the U.S.

(pc/kg)

Year of Harvest	Average from 9-15 States Weighted for Production (HASL) 1/: Wheat	Flour	Average of Pared Samples (FDA) 2/: Wheat	Flour	FDA Sampling Program: Wheat
		Observed			
1959	48	9	--	--	--
1960	26	4	13	4	17
1961	23	7	19	4	18
1962	--	--	--	--	56 3/
		Predicted			
1962 3/	130	22			
1963	250	40			
1964	100	16			
1965	50	8			

1/ (HASL) Health and Safety Laboratory, USAEC, New York

2/ (FDA) Food and Drug Administration, Department of Health, Education and Welfare. The "Paired Samples" indicates that the same sample of wheat was analyzed when made into flour.

3/ Incomplete - includes less than 50% of production. The 1962 predicted value is presented pending the availability of more complete data.

TABLE 9

Average Strontium-90 Content of Human Bone in the U.S.

(pc Sr^{90}/g Ca)

	"Wet" Areas	"Dry" Areas
	Observed (0-4 years old)	
1958 1/	2.0	2.0
1959	2.7	2.2
1960	2.4	1.8
1961	2.6	0.9
1962 (6 months)	2.9	1.0
	Predicted (New Bone) 2/	
1963	12	9
1964	8	5
1965	5	3

1/ Data for 1958-60 are from Lamont Geological Observatory, 1961-62 are from HASL.

2/ One-fourth the predicted total diet values in Table 5.

TABLE 10

Radionuclide Concentrations in Pasteurized Milk

(pc/1. of milk)

Year	Strontium-90				Strontium-89				Cesium-137				Iodine-131			
	"Wet"	"Dry"	A.2/	H.3/	"Wet"	"Dry"	A.2/	H.3/	"Wet"	"Dry"	A.2/	H.3/	"Wet"	"Dry"	A.2/	H.3/
1959 1/ Annual average level	14	9	-	-	30	20	-	-	65	55	-	-	<10	<10	-	-
1960 Annual average level	9	5	7	4	<5	<5	<5	<5	10	10	10	20	<10	<10	<10	<10
1961 Annual average level	9	6	8	5	15	5	15	<5	10	10	10	20	20	20	60	<10
1962 Annual average level	15	10	10	5	55	38	51	27	49	36	37	27	29	36	104	12
1st Quarter 1963 3-month average level	18	11	11	8	40	30	20	55	75	65	65	55	<10	<10	10	20

1/ Based on raw milk data; dash (-) indicates no raw milk station. (Table prepared from USPHS data)

2/ Alaska

3/ Hawaii

TABLE 11

Average Cesium-137 Measured and Predicted Concentrations in Man and Milk

	In Man 2/			In Milk "Wet" Areas 3/
	Measured			
	Washington D. C.	Los Alamos	Average	
1957	-	51	-	
1958	69 1/	62	-	
1959	67	74	70	65
1960	51	67	60	10
1961	31	-	30	10
1962	-	-	-	49
		Predicted		Predicted
1963			150	140
1964			120	70
1965			80	30

1/ July-December only.

2/ Units, picocuries per gram of potassium.

3/ Units, picocuries per liter of milk. (USPHS Data)

SECTION V

RADIATION DOSE ESTIMATES

Exposure from Testing Conducted in 1962

5.1 Radiation doses that could affect present and future generations as the result of nuclear weapons testing conducted through 1961 were reported in FRC Report No. 3, "Health Implications of Fallout from Nuclear Weapons Testing through 1961." The present report considers doses attributable to the tests conducted in 1962 separately from the cumulative doses attributable to all tests conducted through 1962. The major interest is to isolate as much as possible the effects of the fallout rates expected from 1962 through 1965. Results from tests conducted in 1962 are shown in Table 12. Estimates of doses from short-lived nuclides, cesium-137, strontium-89, and strontium-90 were based on measurements made through March 1963 plus the predicted fallout deposition through 1965 in order to emphasize the information which is important in the immediate future. This procedure leaves a small percentage of the debris unaccounted for since it will still be in the stratosphere in 1965. However, the short-term carbon-14 estimates and the bone and bone marrow estimates would not be changed substantially. Estimates of radiation doses incurred in 1962 from tropospheric fallout were based on surveillance data as shown in Table 10.

5.2 Predictions shown in Table 12 of future doses from external radiation from debris yet to be deposited are based on projected deposition rates for "wet" areas of the U.S. as given in Table 4. The levels of cesium-137 were taken to be 1.7 times the level of strontium-90. Estimates of the possible contributions from short-lived nuclides were based on an apparent age of fission debris in the stratosphere corresponding to a mean production time of mid-September 1962, and the estimated levels of these nuclides relative to strontium-90 at the time of deposition. The estimated doses were then calculated, making corrections for weathering, shielding, and the movement of different radionuclides through the environment to man.

5.3 The period of the test moratorium from 1959 to 1961 was sufficient for a peak level of radionuclides such as strontium-90 and cesium-137 to occur and for subsequent downward trends in levels of these radionuclides to be established. The period was not sufficient to define the effective rates of removal of these radionuclides from the biosphere in the absence of deposition of addditional fallout. The effective half-times in the environment for these radionuclides and their biological availability are, therefore, subject to uncertainty, and dose estimates in this report should be considered in that light.

5.4 Whole body and reproductive cell doses from both short-lived and long-lived radionuclides from 1962 tests were considered to begin during 1962. External exposures from cesium-137 were assumed to dimminish with an effective halftime of ten years. Exposures to external short-lived radionuclides and short-lived internal emitters such as strontium-89 and barium-140 --- lanthanum-140 were considered to be completed within about one year following the 1962 tests.

5.5 Strontium-90 is expected to be effectively removed from that part of the biosphere which is important to man with an effective half-time of ten years. Therefore, doses for bone and bone marrow from 1962 tests were predicted for infants born in 1963 since this is the most sensitive age group and is expected to have the maximum concentration of strontium-90 per gram of calcium as discussed in Section IV of this report. Similarly, this is the age group expected to receive the highest lifetime bone dose from tests conducted in 1962.

5.6 The whole-body and bone doses to people deriving their foodstuffs from "dry" areas of the U.S. are estimated to be somewhat less (possibly as much as one-third to one-half) than those deriving their food from "wet" areas. Individuals and population groups subsisting on diets differing greatly from the diet typical of the majority of the population in "wet" and "dry" areas of the U.S. are expected to receive doses both higher and lower than the average dose for the "wet" area presented in Table 12. Although some individuals in the U.S. will receive doses higher than for "wet" areas and some will receive doses lower than for "dry" areas, it is expected that doses differing from these average values by more than a factor of 10 will not occur.

5.7 For calculations of 30-year and 70-year doses, exposure to carbon-14 from 1962 tests of 217 MT total yield (Table 2) was assumed to be reduced with a mean time of 48 years (see Glossary), or a half-time of 33 years. Since the total yields of tests conducted in 1962 are about two-thirds of the total yield from tests conducted through 1961, the long-term doses from carbon-14 from 1962 tests will be almost the same as the long-term doses from carbon-14 discussed in FRC Report No. 3.

Doses from all Tests through 1962

5.8 Estimates of doses to people in the U.S. in "wet" areas from exposure to fallout radioactivity produced by all nuclear tests conducted through 1962 are presented in Table 13. These estimates are based upon observed levels of deposited radioactivity and observed levels of radioactivity in people for "wet" areas through 1962 and upon annual deposition levels of radioactivity expected to occur in "wet" areas through 1965.

5.9 Whole-body and reproductive cell doses from both short-lived and long-lived radionuclides produced by all tests were estimated for population in the U.S. born prior to beginning of nuclear testing. These doses are assumed to be independent of age groups within the population. Based primarily upon measurements of radioactivity in 1961 and 1962, 30-year and 70-year doses related to tests through 1961 are now estimated to closely approximate the lower number of the range of estimated values for whole-body and reproductive cells presented in Table I of FRC Report No. 3 (30-year, whole body and reproductive cells both 60 millirems; 70-year, whole-body and reproductive cells both 70 millirems;) The estimates of whole-body and reproductive cell doses for all tests through 1962 in Table 13 of the current report will be found to be the sum of whole-body doses from all tests through 1961 (shown in Col. 1 of Table 13), plus the estimated whole-body and reproductive cell doses from 1962 tests presented in Table 12, and repeated as Col. 2 in Table 13.

5.10 The doses to bone and bone marrow from all tests through 1962, presented in Table 13, will not be the sum of estimated bone doses in FRC Report No. 3 (Col. 1 of Table 13) plus doses from 1962 tests in Table 12 of this report. The doses to bone and bone marrow were estimated for the age group in the population expected to receive the highest doses from all tests through 1962. The age group considered was infants born in 1963. This determination was based upon a review of measured values of strontium-90 in human bone samples obtained from the beginning of testing through the first six months in 1962, predicted levels in new bone and bone being re-formed or exchanged metabolically from 1963 through 1965, and whole body doses for infants born during various years since testing began.

5.11 Doses to bone and bone marrow in Table 13 are very little higher than those estimated for tests through 1961 and presented in Table I of FRC Report No. 3. The reason for such results is that measured levels of strontium-90 deposition were less in 1962 than had been predicted.

5.12 Doses to bone and bone marrow for the adult population in the U.S. are expected to be smaller than the doses to the most sensitive age group of children.

5.13 Doses to people in "dry" areas of the U.S. from all tests through 1962 are estimated to be about one-third to one-half those for people in "wet" areas. The lower deposition levels in the "dry" areas reduce the exposure from sources external to the body, and lower the concentrations of radionuclides in locally produced food.

5.14 Thirty-year and 70-year carbon-14 doses from tests through 1962 were estimated using a total yield of 459 MT[1/], a production rate of 2 x 10^{26} atoms carbon-14 per MT total yield, and a dose rate of 1 millirem per year for naturally occurring carbon-14. The exposure from carbon-14 was assumed to be reduced with a mean time of 48 years, the time calculated for exchange between the atmosphere and the vast carbon reservoir in the oceans.

5.15 It was estimated in FRC Report No. 3 that carbon-14 from weapons testing conducted through 1961 would lead to an average per capita whole-body and reproductive cell dose of 10 to 15 millirems in the first thirty years. This was estimated to equilibrate eventually at a level of about 0.75 millirem per generation, and this would continue for hundreds of generations. Since testing conducted in 1962 contributed almost an equal amount of carbon-14, the above values may be doubled to arrive at the long-term doses that are now predicted.

Thyroid Doses from Iodine-131

5.16 Doses to the thyroid due to iodine-131 in fallout have occurred during and immediately following periods of nuclear testing. The Public Health Service's Pasteurized Milk Network reported no iodine-131 at detectable levels in the interval from 1959 through August 1961. Table 10 shows that following resumption of nuclear testing in September 1961, iodine-131 was found generally throughout the nation in zones of both high and low

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1/ Based on the sum of the total yields for air detonations and one-half the total yields of surface detonations from Table 1 of this report.

precipitation. Limited in vivo measurements in the fall of 1961 and in 1962 support a conclusion that fresh milk is the principal source of iodine-131 exposure to the thyroid gland in a large proportion of the population.

5.17 The relationship between iodine-131 intake and thyroid dose is based on the biological model derived in FRC Report No. 2. An estimated annual average daily intake of 80 [1/] picocuries of iodine-131 would result in an average dose of 500 millirems in one year to a suitable sample of exposed infants in which the thyroid weight is taken as two grams. This condition applies approximately to the age group from 6 to 18 months. With children above approximately 18 months of age the dose to the thyroid would become progressively smaller with the increase in size of the thyroid to a value in the adult of approximately one-tenth the value in infants.

5.18 Estimates of iodine-131 dose to the thyroid developed for infants 6 to 18 months of age on the basis of the above relationship between intake and dose, assuming one liter of fresh milk consumption per day, ranged from 30 to 440 millirems in 1961 and from 30 to 650 millirems in 1962. These values are estimates of thyroid dose for high and low individual stations in the pasteurized milk network for the years indicated. It has been estimated that a small number of infants in localized areas conceivably could receive doses from 10 to 30 times the average.

1/ "Using the known factors and the assumptions enumerated above, it can be calculated that an average daily intake of 80 micromicrocuries of iodine-131 per day would meet the RPG for the thyroid for averages of suitable samples of an exposed population group of 0.5 rem per year. As stated in Section I, it is appropriate to specify three ranges of transient rates of daily intake in order to provide guidance for the Federal agencies in the extablishment of operating criteria. For this purpose, the value of 80 micromicrocuries per day has been rounded off to 100 micromicrocuries per day as being more in keeping with the precision of the data." (Paragraph 2.14, FRC Report No. 2).

TABLE 12

Estimated Radiation Doses in the "Wet" Areas from Testing Conducted in 1962

(Doses expressed in millirem)

Tissue or Organ	Radiation Doses 30-year	70-year
Whole body and reproductive cells		
Cesium-137 external	9	10
Cesium-137 internal	9	10
Short-lived nuclides	18	18
Carbon-14	11	18
TOTAL	47	56
Bone		
Strontium-90		180
Strontium-89		39
Whole body		56
TOTAL		275
Bone Marrow		
Strontium-90		60
Strontium-89		13
Whole body		56
TOTAL		129

TABLE 13

Estimated Radiation Doses in the "Wet" Areas of the U.S. from all Nuclear Weapons Testing Conducted Through 1962

(Doses expressed in millirem)

Tissue or Organ	From Tests Conducted Through 1961 1/	From Tests Conducted in 1962	From all Tests Conducted Through 1962	From Natural Background
Whole Body and Reproductive Cells				
1 year	10-25	24		
30 years	60-130	47	110 2/	3,000
70 years	70-150	56	130 2/	7,000
Bone				
1 year	30-80	83		
70 years	400-900	275	465 3/ 4/	9,100
Bone Marrow				
1 year	20-40	44		
70 years	150-350	130	215 3/ 4/	7,000

1/ Taken from Table 1, FRC No. 3. Based on surveillance measurements made in 1962, the actual exposures are expected to correspond to the low end of the reported range. Actual exposures to bone and bone marrow are now expected to be even lower than the reported range.

2/ The whole body dose is based on the average person receiving the highest exposure assuming that the person was born prior to the beginning of testing. Current estimates indicate that from tests conducted through 1961, the whole body and reproductive cell doses for 30 and 70 years will be 63 and 74 millirems respectively.

3/ The bone and bone marrow doses are caluclated for the average person born in 1963 since it is believed that this person might receive the highest bone dose of any age group.

4/ Doses in previous columns are not additive; see paragraph 5.10.

SECTION VI

EVALUATION

6.1 The Federal Radiation Council reported on the health implications of fallout from nuclear weapons testing through 1961 in FRC Report No. 3, issued in May 1962. (Copy attached) The doses were evaluated by comparison with the doses due to naturally occurring sources of radiation following the procedures developed over the past several years through studies conducted by the National Academy of Sciences, the United Nations Scientific Committee on the Effects of Atomic Radiation, the National Committee on Radiation Protection and Measurements, the International Commission on Radiological Protection, and the fallout prediction panels convened by the Joint Committee on Atomic Energy in 1957, 1959, and 1962. Two types of biological effects are of concern; effects induced by exposure of the reproductive cells (genetic effects), and possible effects on persons now living (somatic effects) resulting from the exposure. Both types of effects have been considered and evaluated by the National Academy of Sciences Committee on the Biological Effects of Atomic Radiation and the conclusions of this committee have been accepted by the Federal Radiation Council as the basis for the scientific aspects of the present evaluation.

6.2 The genetics subcommittee of the National Academy of Sciences Committee on the Biological Effects of Atomic Radiation has recommended that the genetically effective per capita dose during the first thirty years of life be limited to 10 Roentgens (equivalent to 10,000 millirems as used in this report) from all man-made sources, including medical exposures.

6.3 The revised estimates of the short-term per capita effective dose to the reproductive cells show that weapons tests conducted during 1962 will be about 47 millirems. All tests conducted through December 1962 will result in a per capita 30-year dose of about 110 millirems. This is about one-hundredth of the amount recommended by the National Academy of Sciences. These values are considerably less than the corresponding 30-year dose of 3,000 millirems from naturally occurring sources during the same period. Similarly, the variations in dose-rate from worldwide fallout in different parts of the country are less than the variations in dose-rate from naturally occurring sources in the inhabited parts of the world. Further, comparison with the 5,000 millirems per generation proposed previously by the Federal Radiation Council as a level of genetic risk that would be acceptable to gain the benefits of nuclear energy from normal peacetime operations and the 10,000 millirems per generation recommended by the NAS Subcommittee on Genetics as a "reasonable quota" for man-made radiation exposure of the general public indicates that present and anticipated levels of fallout do not constitute an undue risk to the genetic future of the nation.

6.4 The genetically significant dose per generation attributable to tests conducted through 1962 will be greatly reduced in later generations. The total dose which may come eventually from material still in the stratosphere in 1966 plus the long-term effects from carbon-14 may be somewhat larger than the estimates reported. Thus, the ultimate genetic effects attributable to weapons tests conducted in 1962 are expected to be nearly as much as that from all tests conducted prior to 1962.

6.5 In addition to the possible influence of weapons testing on heredity, the possibility of adverse health effects on persons now living is of concern to the Council. The estimates in Table 13 show that testing conducted through 1962 is expected to result in cumulative whole-body doses over a 70-year period from radionuclides external to the body and radionuclides in the body of about 130 millirems. The biological effect of concern is the induction of serious diseases such as cancer that might result from irradiation of the whole body.

6.6 The Subcommittee on Pathological Effects of the National Academy of Sciences Committees on the Biological Effects of Atomic Radiation (1960) concluded that as long as the criteria for the effective genetic exposure were met, any possible effects on the health of the persons exposed would be much too small to be perceptible. However, the special cases of iodine-131 and strontium-90 which deposit preferentially in the thyroid and bone respectively were pointed out as possible exceptions to the evaluation. The Council, therefore, concludes that except for iodine-131 and strontium-90, the estimated whole-body doses from present and anticipated levels of fallout do not constitute an undue risk in terms of direct effects on the individuals exposed.

Evaluation of Iodine-131

6.7 The special case of iodine-131 has been recognized by the Federal Radiation Council. The known experience in the U.S. related to iodine-131 in milk from 1959 to the present is summarized in Table 10. The data are reported in terms of the average daily intake of iodine-131 over a 12-month period assuming a consumption of 1 liter of milk per day to correspond to the cumulative levels of iodine-131 actually observed at the regular milk sampling stations. The corresponding radiation dose for the average infant thyroid in the highest region has a calculated value of 620 millirems. In the special case where nearly all of the annual intake could come from exposure to abnormally high concentrations in a local area, resulting from a single nuclear explosion of low yield, the Council recognized that some small number of individual infants could conceivably receive doses 10 to 30 times the average for the area as a whole.

6.8 Based on the advice of a special panel convened by the Council in the summer of 1962, it was concluded that radiation doses to the thyroid many times higher than those provided in FRC Report No. 2 would not result in a detectable increase in diseases such as thyroid cancer. No case of thyroid cancer in man ascribable to radioactive iodine used in the medical diagnosis and treatment of thyroid disease has yet been established. The radiation doses administered for diagnosis and treatment of thyroid disorders have ranged up to thousands of times higher than the 1.5 rems per year recommended as a Radiation Protection Guide in FRC Report No. 2 for exposure to individuals due to iodine-131 released to the environment from normal peacetime operations.

6.9 The Council concluded in September 1962 that iodine-131 exposures at the levels existing then, involve health risks so slight that countermeasures applied to the food industries might have an adverse, rather than favorable effect on public well-being. It is similarly concluded in this report that iodine-131 doses from weapons testing conducted through 1962 have not caused an undue risk to health.

Evaluation of Strontium-90

6.10 The health risk from strontium-90 arises from the fact that it is taken into the body with calcium and is deposited in the skeleton. Once incorporated into the skeleton, it causes radiation doses to the skeleton at a continuously decreasing rate during the entire life of the individual. The lifetime doses to the age group receiving the highest doses from radionuclides in fallout are expected to be about 465 millirems for bone and 215 millirems for bone marrow. Of this exposure, it is estimated that the average concentration of strontium-90 in new bone at its maximum value from fallout associated with all weapons testing conducted through 1962 may reach about 12 picocuries strontium-90 per gram of calcium, although by metabolic activity this would soon drop to an average concentration in the whole skeleton of about 7 picocuries per gram of calcium. This would give an initial dose rate to new bone of 36 millirems per year and to bone marrow of 12 millirems per year. When redistributed, the dose rates would be 21 millirems per year to bone, and 7 millirems per year to bone marrow.

6.11 The Council has evaluated the possible need and desirability of instituting national programs for modifying the diet, removing strontium-90 from food supplies such as milk, or otherwise limiting the annual intake of strontium-90. A general appreciation of the contribution of strontium-90 to health risks can be gained by comparing the lifetime radiation dose of 465 millirems to bone with the corresponding dose of 9,100 millirems from natural sources; the radiation dose of 215 millirems to bone marrow with the corresponding dose of 7,000 millirems from natural sources.

6.12 With specific reference to strontium-90, the Council has re-examined its recommendations for skeletal burdens of strontium-90 which have been judged to be an acceptable risk to gain the benefits of normal peacetime operations. The selection of these skeletal burdens reflect the simultaneous judgment that the corresponding risks to health are too small to warrant actions that would interfere with or disrupt the normal utilization of food. The skeletal burden of strontium-90 corresponding to the Radiation Protection Guide recommended in FRC Report No. 2 for limiting the exposure of the skeleton is 150 picocuries of strontium-90 per gram of calcium. However, since no operating need for exposures this high was foreseen, the recommended level was reduced to 50 picocuries of strontium-90 per gram of calcium, corresponding to a sustained dietary intake of 200 picocuries of strontium-90 per day. The skeletal burdens of strontium-90 from present and anticipated levels of fallout are well below these values.

6.13 On the basis of the preceding considerations, it is concluded that the health risks from present and anticipated levels of strontium-90 from fallout due to testing through 1962 are too small to justify measures to limit the intake by modification of the diet or altering the normal distribution and use of food. It is further concluded that since milk and dairy products are the major sources of calcium in the U.S. diet and since these products have a lower concentration of strontium-90 in relation to calcium than the total diet, restriction or reduction in the normal use of these food products would be unwise.

Future Indications

6.14 Looking into the future, the Council notes that the highest annual dose rates have been associated with the short-lived radionuclides and tropospheric fallout. How much these annual transients contribute to the cumulative lifetime exposures depends, of course, on the frequency with which test programs occur. This review has shown that the testing programs of 1961 and 1962 reached higher levels of fission and total yields than any previous comparable period, and the radionuclides associated with tropospheric fallout were correspondingly evident.

6.15 Renewed attention has been directed to the special case of iodine-131, and the pathways by which it passes through the environment to man. Studies conducted by the Department of Agriculture and the U.S. Public Health Service in 1962 have demonstrated the effectiveness of reducing the iodine-131 levels in milk by adjusting the source of feed used by the dairy cattle if such action is needed. Also, the Atomic Energy Commission has recently initiated a program at the Livermore Radiation Laboratory to gain a better understanding of the processes affecting the distribution of fallout and its movement through the environment. Iodine-131 is included among the nuclides of interest to this program.

6.16 As to long-lived radionuclides such as strontium-90 the Council notes that processes for the removal of radionuclides from milk developed jointly by the Department of Agriculture, the Public Health Service, and the Atomic Energy Commission are now being evaluated for the feasibility of full-scale production for possible use in an emergency.

6.17 However, in the Council's judgment, major national programs directed at tremoving strontium-90 from food supplies would not contribute to the national welfare at present or projected levels of strontium-90. Even if the strontium-90 levels in human bone reached those corresponding to the Radiation Protection Guide established for the control of normal peacetime operations, the removal of strontium-90 from foods would not necessarily be in the best interests of the nation. The Council would have to consider whether the health risk would be great enough to justify the total impact of such a program on the economy and the necessary allocation of national resources in relation to the health benefits that might be achieved through feasible reduction in strontium-90 intake.

GLOSSARY OF TERMS

Absorbed Dose The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest.

Activity The number of disintegrations of a quantity of radionuclide per unit time.

Average Dose The arthmetic mean radiation dose. The average may be taken with respect to time, number of people, location, or the dose distribution in tissue.

Beta Radiation Swiftly moving electrons emitted by radioactive substances. Strontium-90, strontium-89, and carbon-14 all emit beta particles.

Biological Half-life The time taken for the body burden of a radionuclide to be reduced by biological removal processes to one-half its initial value. Radioactive decay is not involved.

Body Burden The amount of a specified radioactive material or the summation of the amounts of various radioactive materials in a person's body at the time of interest.

Critical Organ An organ or tissue most affected by ionizing radiations from the deposition of a specified internal emitter or from external sources. The reproductive cells are considered the critical tissue for genetic effects. The thyroid is considered the critical organ for the effects from radioactive iodine. Bone and bone marrow are considered the critical organs for the effects from strontium-90.

Curie A measure of the activity (rate of disintegration or decay) of a radioactive substance. One curie equals 3.7 x 10^{10} nuclear disintegrations per second, or 2.2 x 10^{12} per minute.

Megacurie (MC) One million curies. A fission yield of 10 megatons creats approximately 1 megacurie of strontium-90.

Millicurie (mc) One-thousandth of a curie. Also one thousand microcuries.

Microcurie (μc) One-millionth of a curie.

Picocurie (pc) One micromicrocurie ($\mu\mu$c). This is one-millionth of a microcurie or one-millionth-millionth of a curie. It corresponds to a rate of radioactive decay equivalent to 2.2 disintegrations per minute.

Dose A measure of the energy absorbed in tissue by the action of ionizing radiation on tissue. As used in radiation protection, definitive practice requires that the term be used in such combining forms as radiation dose, absorbed dose, whole-body dose, and partial-body dose.

Dose-effect Relationship The magnitude of a specific biological effect, expressed as a function of the radiation dose producing it. It is frequently represented as a curve described as a dose-effect curve, dose-effect response curve, or dose response curve.

Dose Equivalent A concept used in radiation-protection work to permit the summation of doses from radiations having varying linear energy transfers, distributions of dose, etc. It is equal numerically to the product of absorbed dose in rads and arbitrarily defined quality factors, dose distribution factors and other necessary modifying factors. In the case of mixed radiations, the dose equivalent is assumed to be equal to the sum of the products of the absorbed dose of each radiation and its factors.

Effective Half-life or Half-time The time taken for the total number of atoms of a radioactive nuclide to be reduced to one-half of its initial value by combined radioactive decay and biological removal processes.

Environment The physical environment of the world we live in consisting of the atmosphere, the hydrosphere, and the lithosphere. The biosphere is that part of the environment supporting life and which is important to man.

Exposure A measure of x and gamma radiation at a point. However, it is often used in the sense of being made subject to the action of radiation.

External Exposure The exposure of body tissues to ionizing radiation originating from sources outside the body.

Fallout The process or phenomenon of the fallback to the earth's surface of particles contaminated with radioactive material from the radioactive cloud. The term is also applied in a collective sense to the contaminated particulate matter itself. The early (or local) fallout is defined, somewhat arbitrarily, as those particles which reach the earth within 24 hours after a nuclear explosion. The delayed (or worldwide) fallout consists of the smaller particles which ascend into the upper troposphere and into the stratosphere and are carried by the winds to all parts of the earth. The delayed fallout is brought to earth, mainly by rain and snow, over extended periods ranging from months to years.

Internal Exposure The exposure of body tissue to ionizing radiations originating from radionuclides contained within the body.

Whole-body Exposure Literally, the exposure of the whole body.

Fission The process whereby the nucleus of the particular heavy element splits into (generally) 2 muclei of lighter elements, with the release of substantial amounts of energy. The most important fissionable materials are uranium-235 and plutonium-239.

Fission Products A general term for the complex mixture of substances produced as the result of nuclear fission. Something like 80 different fission fragments result from approximately 40 different modes of fission of a given nuclear species. The fission fragments, being radioactive, immediately begin to decay, forming additional radioactive products with the result that the complex mixture of fission products so formed contains about 200 different isotopes of 36 elements. For example, iodine-131, being a daughter element with several preceding radioactive parents, reaches its maximum production approximately 7 hours after the detonation of a fission device.

Fission Yield The equivalent energy released as the result of nuclear fission. The production of fission products is proportional to the fission yield.

Fusion The process whereby the nuclei of light elements, especially those of the isotopes of hydrogen, combine to form the nucleus of a heavier element with the release of substantial amounts of energy. These are so called thermonuclear reactions because very high temperatures are used to bring about the fusion of the light nuclei. Neutrons, leading to the production of carbon-14, are produced by this reaction; however, fission products are not.

Gamma Rays Electromagnetic waves of very short wave lengths produced during the disintergration of radioactive elements. Like x-rays, they readily penetrate body tissues.

Genetic Effect A change in a reproductive cell which would alter the characteristics of an individual produced from the affected cell or which causes a mutation that may be inheritable by subsequent generations.

Half-life The time required for the activity (the disintegration rate) of a radioactive nuclide to decay to one-half of the initial value.

Internal Emitters Radionuclides contained within the human body.

Isotopes Atoms of the same element, i.e., having the same atomic number, but of differing atomic weights. The isotopes of an element have closely similar chemical and physical properties, but differ in atomic mass (due to different numbers of neutrons in the atomic nuclei) and in their nuclear properties (e.g., stable, radioactive, fissionable, etc.). Nearly all elements found in nature are mixtures of several isotopes. (See nuclide)

Mean or Average-lifetime A particular radioactive atom can decay now, later, or never. However, the average or mean-life expectancy of a number of the same radionuclides is a definite quantity and is equal to 1.4 times the half-life. Analogous terms are often used to express changes in radionuclide concentrations in different compartments of the environment as a function of time. For example, the rate of disappearance of carbon-14 from the atmosphere as the result of diffusion into the ocean, the biosphere, and other environmental compartments has been expressed in terms of a half-time of 33 years and a mean-time of 48 years.

Megaton Yield A nuclear detonation which releases a total energy equivalent to one million tons of TNT.

Natural Background Radiation Ionizing radiations from naturally occurring radionuclides as they exist in nature plus cosmic radiation.

Normal Peacetime Operations The peaceful applications of nuclear technology where the primary radiation protection control is placed on the design and use of the source.

Nuclide An atom of a particular species or element; that is, characterized by an atomic number and an atomic weight. Carbon-14 is a nuclide. Carbon as it occurs naturally consists of 3 nuclides; carbon-12, carbon-13, and carbon-14, which together bear the relationship of isotopes.

Organ or Tissue Dose The radiation dose received by a particular body organ or tissue. The radiation may be from an external or an internal source.

Population Dose The radiation dose received by members of a population. It is usually estimated as that dose which would be received by the average member of the population under consideration.

Radiation Effect A response or change induced by exposure to ionizing radiation.

Radiation (Ionizing) Radiation capable of producing ions in a medium, particularly tissues of the human body. Examples are x-radiation and gamma radiation, beta radiation, and cosmic radiation.

Radiation Protection Guide (RPG) The radiation dose which should not be exceeded without careful consideration of the reasons for doing so; every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable.

Radioactivity The property or process whereby certain isotopes or nuclides spontaneously disintegrate emitting particles and/or gamma rays by the disintegration of the atomic nuclei. (See activity)

Radionuclide A radioactive nuclide.

Rem A special unit of dose equivalent. It is that quantity of any type of ionizing radiation which, when absorbed in the human body, produces an effect equivalent to the absorption of 1 roentgen of x or gamma radiation at a given energy.

Seventy-year Somatic Dose That whole-body dose received by tissues other than the reproductive cells over a period of 70 years. When calculated for exposures from fallout this dose includes contributions from whole-body radiation from external sources, cesium-137 taken internally, and carbon-14.

Somatic Effect A change (other than genetic) produced in any tissue which alters the normal body processes of the irradiated individual.

Stratosphere A relatively stable layer of the atmosphere lying above the tropopause. For the purpose of this document, the lower stratosphere is defined as the first few tens of thousands of feet above the tropopause and the upper stratosphere as the layer to about 150,000 feet.

Stratospheric Fallout Fallout associated with weapon debris which was initially injected above the troposphere into the stratosphere. This is the component that results in worldwide distribution of fallout from the testing of nuclear weapons.

Strontium Unit (SU) One picocurie of strontium-90 per gram of calcium, usually in bone but now extended to items of food and milk.

Thirty-year Genetic Dose The dose estimated to be received from all sources by the reproductive tissues for a period of 30 years. When computed for fallout exposures this includes whole-body doses from external sources, gamma radiation from cesium-137 in the body, and carbon-14. Recent reports indicate that strontium-90 may also be a minor contributor.

Tropopause The boundary between the troposphere and the stratosphere. It normally occurs at an altitude of about 30,000 to 40,000 feet in polar and temperature regions and about 55,000 feet in the tropical and equatorial regions.

Troposphere That portion of the atmosphere below the stratosphere. It is that portion in which temperature generally decreases rapidly with altitude, clouds form, and which is associated with all of what we generally know as "weather." The altitude of the troposphere varies from the equator to the poles and from winter to summer.

Tropospheric Fallout The deposition of radioactive weapons debris which was initially injected into the troposphere and not deposited as local fallout.

Yield The total effective energy released in the nuclear explosion. It is usually expressed in terms of the equivalent tonnage of TNT required to produce the same energy release in an explosion.

REPORT NO. 3

health implications of fallout from nuclear weapons testing through 1961

May 1962

Report of the

FEDERAL RADIATION COUNCIL

CONTENTS

REPORT OF THE FEDERAL RADIATION COUNCIL

HEALTH IMPLICATIONS OF FALLOUT FROM NUCLEAR WEAPONS TESTING THROUGH 1961

The Federal Radiation Council has considered available information on radiation doses and possible health effects of atmospheric nuclear weapons testing. Before discussing the estimates made in this report in detail, it is appropriate to point out the difficulties of being precise in this field.

Although a large and expanding program for measuring radiation levels at a number of locations throughout the United States has been in effect for a number of years, the application of such data to the whole country, to an extended time period, or to the entire population involves assumptions than can not be completely validated. Furthermore, while a considerable body of information has been accumulated on the effects of radiation on animals and man, the possible effects of low doses delivered at low dose rates are insufficiently known to permit firm conclusions about the extremely low exposures resulting from fallout. Current experimental techniques are not good enough to detect biological effects at the low levels of worldwide fallout from nuclear tests.

Any possible manifestations resulting from fallout radiation will not be unique, for all of the diseases and disabilities known to be caused by radiation also occur for other reasons. Whatever effects might be produced by fallout could only be reflected in statistical increases in the number of conditions already present in the population. Any individual effects would be so diluted by space and time that they would not be recognizable among the much larger number of identical effects arising from other causes, among which they would be interspersed.

Finally, any proper understanding of estimates in this field must take into account the many different ways in which similar or even identical data can be expressed. Many of the apparent differences among scientists arise from different forms of presentation. Two approaches have been used. One estimates the risk of damage to a single person. This risk is extremely small in comparison with others which people normally accept. The second approach considers possible effects on a large population for a year or a generation or for several generations totaling hundreds of years. Even a very small proportion of affected individuals will, in a very large population for a long period of time, amount to an impressive total number of individuals.

Estimated Radiation Exposure from Testing

Any consideration of possible health effects from fallout must begin with the radiation doses to which people are exposed as a result of such tests.

A sharp distinction must be made between the devastating effects of "local" fallout in a nuclear attack on an unshielded population and the effects of fallout from weapons testing. Weapons testing creates far smaller total amounts of fission products so that its fallout is far less than that which would result from nuclear war. Furthermore, the tests are planned to avoid local fallout or to confine it to locations where it will have minimal effects. Hence, in weapons testing the problem is largely confined to delayed fallout which decays greatly in the upper atmosphere and is dispersed at low concentrations over the earth's surface. This report is concerned primarily with the effects of such delayed fallout.

Dose estimations must take into account exposure from all sources; external, and internal through ingestion of food and water and inhalation. Some radioactive elements may concentrate to different extents in various parts of the body. Those which tend to concentrate in a certain organ will selectively irradiate that organ. Thus a thyroid dose, for example, represents the sum of the whole-body dose from a variety of substances plus the extra dose from iodine-131, an element which tends to concentrate in the thyroid gland. In addition, some elements are taken up more effectively at one age than another. For example, the proportion of strontium-90 retained in the growing bones of children is greater than that retained in the bones of adults ingesting the same foods. Furthermore, different sources of radiation give off different kinds of radiation having different biological effects, so that doses cannot be directly compared. These points should indicate the difficulty of referring to any one exposure level from a particular source without identifying what kind of a dose and what part of the body is involved.

Estimates of doses from fallout from tests through 1961 in millirems, a unit of ionizing radiation dose, are given in Table I and discussed further in Appendix "A". Because of uncertainties and the variety of necessary assumptions, these estimates are expressed as ranges of values within which the average exposure over the United States is expected to lie. The values given apply to the United States, and are somewhat higher than those for most of the rest of the world. Doses to the whole-body and reproductive cells represent an average for all age groups in the entire population. Doses to bone and bone marrow are average values for those who were infants at the time of highest concentrations of the particular isotopes irradiating these organs; values averaged for all age groups will be lower.

The half-life of radioactive iodine, the principal source of the thyroid dose, is only 8 days and the peak dose rates persist for a relatively short period of time. For this reason thyroid doses are not included in the table. Doses to the thyroid from the major past tests were estimated to have ranged from 100 to 200 millirems per year during and immediately following periods of testing. These values apply only to individuals who were infants at the time of highest concentration of radioactive iodine. The average value for all age groups was about a tenth as much. Although data from which thyroid doses during 1957-58 can be estimated are limited, it is likely that there was much geographic variation, and in some limited areas of the United States the average thyroid doses were probably many times the national average.

The whole-body dose due to the carbon-14 produced by all tests through 1961 has been included but not separately listed in Table I. It is estimated to total from 10 to 15 millirems during the first thirty-year period. The dose rate will decrease much more rapidly than would be predicted on the basis of the carbon-14 radioactive half-life of 5,700 years because of the absorption of the radioactive carbon dioxide from the atmosphere into the ocean. After about 200 years the dose rate from carbon-14 will have been reduced to a total of about 0.75 millirem during a thirty-year period.

To put these dose levels in some perspective, Table I compares them with exposures from natural background and with the Radiation Protection Guides of the Federal Radiation Council. The comparisons indicate that doses from fallout have generally been a small fraction of the Guides for population groups.

Background radiation arises from naturally radioactive materials such as carbon-14 and potassium-40 in the human body, radium in the earth's crust, and cosmic radiation from outer space. Man has always been exposed to these radiations. Natural background radiation varies from place to place, both with elevation and with radioactive content of local materials. In the United States these values have been observed to range from 70 to 200 millirems per year. The value for background radiation given in Table I is a weighted average for the entire United States population.

The estimated values given in Table I for whole-body exposures from fallout are considerably less than the exposures from natural sources. Over a period of 30 years the average whole-body dose from all testing through 1961 will be between 60 and 130 millirems compared to 3,000 millirems from background. Thus testing through 1961, including the contribution from carbon-14, will, over this thirty-year period, increase exposures over natural background by less than five percent. Seventy-year average bone doses, when similarly compared, are increased less than ten percent. Any further testing will, of course, increase the exposure.

The fact that exposure from some sources is generally accepted without question should not in itself be a reason for accepting exposure to added levels of man-made radiation. However, comparison of exposure levels with those of natural background does provide some indication of the significance of increases from fallout. One normally considers variation in exposure from natural sources to be of little significance. For example, a resident of the East Coast contemplating a move to a high-altitude location in the West is unlikely to know or attach any importance to the fact that his exposure to background radiation will be appreciably increased—more than twenty-five percent at elevations above one mile.

Another basis of comparison is the radiation exposure received from medical diagnostic procedures in the United States. It has been estimated that a person in the United States will accumulate a genetically effective dose of the order of 1,000 millirems over a thirty-year period. There are, however, wide fluctuations in the exposures to the reproductive cells from the diagnostic procedures.

Estimates of Biological Effects

Much available evidence indicates that any radiation is potentially harmful. However, effects become increasingly difficult to demonstrate below 10,000 millirems, and impossible to detect by present techniques at the very low dose levels from fallout. Nevertheless, it is virtually certain that genetic effects can be produced by even the lowest doses. These effects in the children of exposed parents and all future generations may be of many kinds, ranging from minor defects too small to be noticed to severe disease and death.

In the case of somatic effects, i.e., effects directly on the persons exposed, the evidence is insufficient to prove either that there is a dosage level below which no damage occurs (the "damage threshold" hypothesis) or that there is some risk of damage at any dosage level, no matter how low (the "no threshold" hypothesis). It may well be that some effects are of one kind, some of the other. Dose rate is important; a protracted dose is much less effective than the same total dose given in a short time.

Estimates have been made by national and international groups of scientists of the number of possible adverse health effects that might occur from various exposure levels. Tables II and III apply some

of these estimates to the exposure levels from all testing through 1961 to indicate the possible adverse health effects in the United States population that might result from this testing. United States figures have been used because knowledge of dose levels and of health effects occurring in the absence of testing is more complete for this country than on a worldwide basis. For convenience in expressing the concepts and calculations in this report, the population of the United States has been taken as approximately one-tenth of the population in the same latitudes of the northern hemisphere, and as one-twentieth of the population of the entire world. The figures in Table II on the possible number of adverse health effects from testing through 1961 may be multiplied by 10 to provide a rough estimate of comparable worldwide effects with the exception of carbon-14, for which a factor of approximately 20 must be applied.

Table II and Appendix "B" give numerical estimates of the effects of fallout on one category of genetic effects—severe physical and mental defects. This category includes the hereditary component of such things as congenital malformations, blindness, deafness, feeblemindedness, muscular dystrophy, hemophilia and mental diseases.

In Table II the estimated numbers of radiation effects are given as three values. The upper figure is the best estimate based on radiation-induced mutation rates in mice, and on the spontaneous incidence of these defects in man. The other figures represent the range within which the true value may reasonably be expected to lie.

As shown in the table, about ten percent of the number that may result in all time from weapons tests through 1961 are estimated to occur in the first generation—the children of parents exposed to this fallout. The remaining ninety percent occur in decreasing numbers in succeeding generations. Somatic effects appear only in the irradiated individual himself, and not in his offspring. The manifestations of particular concern are leukemia and other types of cancer.

The radiation dose from carbon-14 is spread over an enormous period of time extending through many thousands of years. The number of mutations from carbon-14, when exposure over all time is considered, is estimated to be greater than from other radioactive elements produced in nuclear detonations. These mutations will, however, be distributed over a much longer time with a much smaller number in any one generation.

In addition to the gross defects listed in Table II, there may be an unknown but probably a considerably larger number of mutations with less obvious effects such as minor physical abnormalities, mild diseases, impairment of physiological functions, and reduced resistance to infection or other stresses of life. Part of this damage will result in a lowered probability of survival at various ages.

Reduced viability of this kind has been consistently found in mouse experiments. The best data on mice are for the infant and embryonic deaths. To the extent that mouse data can be applied to man, the results indicate that the radiation-induced mortality of embryos and infants in the first generation after irradiation is probably larger, perhaps five times larger, than the number of induced defects of the type estimated in Table II. Numerical estimates are not given for such effects because of uncertainties as to the comparability of these effects in mice and humans. This is the viewpoint of those who have done much of the experimental work in this field.

Mutations which have a mild effect on the individual may cause substantial damage in the aggregate. This is because the mildness permits these mutations, such as slight reductions in viability and other less obvious effects, to persist in the population longer than mutations with severe effects, and thus to affect a correspondingly greater number of persons. There are no data which would permit these effects to be assessed with sufficient accuracy to permit numerical estimates.

If, however, numerical estimates are made of all these genetic effects, both those which are likely and those which are more speculative, the aggregate of these estimates when counted as the total number of individuals affected throughout the world in future generations leads to very large numbers. Likewise, large numbers can be obtained when other effects or deaths from any cause are totaled over large populations and many generations. On the other hand, it must be emphasized again that whatever the genetic effects of fallout radiation from weapons testing through 1961 may be, the total effect will certainly be considerably less than that occurring inescapably from background radiation. This, in turn, is considerably less than the effects from other factors which determine the total natural mutation rate.

Estimates for two kinds of somatic effects, leukemia and bone cancer, are given in Table III. As mentioned earlier, it is not known whether or not there is a threshold dose below which these diseases are not produced. If a threshold exists, fallout radiation may produce no additional cases, and the lower limits of zero reflect this possibility.

The upper estimates in Table III are made by assuming the effect of a low dose, delivered at a low dose rate, to be proportional to the effect of a high dose delivered at a higher dose rate. The estimates for the upper limits are probably too high because no allowance had been made for the possibility that a given dose is less effective when received slowly over a long period of time. Thus the range of numbers given in Table III is reasonably certain to bracket the correct value.

There are other possible somatic effects of radiation such as malignancies (other than leukemia and bone cancer) and general effects such as life shortening. Among these malignancies is cancer of the thyroid, a possible effect from exposure to radioiodine. Table III includes no data on the possible incidence of this effect because estimates, like those recognized by national and international groups of scientists for possible leukemia and bone cancer effects, have not been made for cancer of the thyroid. However, from what little is known about the effect of radioiodine, including data obtained from human exposures at very high levels, the likelihood of any possible thyroid effects has been considered to be about the same as other malignancies for comparable exposures. Even less information is available as to possible increases in all these other effects than is available for leukemia and bone cancer.

To put these estimates of possible adverse health effects in some perspective, Tables II and III also include the total number of these same effects occurring in the United States from all causes.

Conclusions

We cannot say with certainty what health hazards are caused by fallout from nuclear testing. We expect there will be some genetic effects; other effects such as leukemia and cancer are more speculative and may not occur at all. We can observe that, compared to the number of these same adverse biological effects occurring wholly apart from testing, the additional cases that might be caused by testing are a very small quantity. We conclude that nuclear testing through 1961 has increased by small amounts the normal risks of adverse health effects.

APPENDIX "A"

EXPLANATORY MATERIAL ON DOSE ESTIMATIONS

The estimates of radiation doses attributable to fallout from tests of nuclear weapons given in Table I have been based on extensive observations and studies through 1961. These estimates include exposures from fallout which already has occurred and from material from past tests yet to be deposited. Estimates are based on measurements of radionuclides in air, rain, soil, water supplies, food, and people.

Table I gives estimates of radiation doses from fallout resulting from tests through 1961. The dose ranges given in this table represent estimates made using somewhat different but plausible assumptions concerning such factors as fallout distribution, the effects of weathering and shielding, and the movement of radioisotopes from the environment to man. It is believed that the best estimates that can be made at the present time would lie within the ranges given.

In the cases of whole body and reproductive cell exposures, radiation doses are relatively independent of age, except for the fact that children born in the past two or three years will have missed much of the exposure from earlier tests experienced by older persons. A large fraction of the dose to the whole-body and reproductive cells from a particular test may be received within a period of months after fallout occurs. The contribution of radioiodine to the dose to the thyroid gland is much larger in the case of infants than in older persons and is effectively complete within a few weeks after a nuclear test.

Radiation doses to the bone and bone-marrow from a particular test will be received at decreasing rates over a period of a lifetime. Early concentrations in the bone will be greatest for those children who are less than one year of age at the time that peak concentrations of fallout occur in food. The average bone and bone marrow doses to such children as estimated in Table I are much larger than the average to the whole population.

It is estimated that carbon-14 resulting from tests through 1961 will produce a radiation dose to the whole body including the reproductive cells of 10 to 15 millirems in the first 30 years, which is less than one percent of the 30 year genetic dose to the present population from natural background.

While carbon-14 decays very slowly with a radioactive half-life of 5,700 years, its availability as a source of radiation exposure initially decreases rather rapidly because of absorption of carbon dioxide from the atmosphere into the oceans. In a period of one or two hundred years, the exchange between the atmosphere and the ocean approaches an equilibrium with most of the carbon-14 in the oceans. This mixing will reduce the carbon-14 due to weapons tests to about two percent of the natural carbon-14 concentration in the atmosphere, biosphere and oceans. The radiation dose rate at this time will be about 0.025 millirem per year, or 0.75 millirem per generation. Although the dose rate is very small, it will continue at a rate which decreases with the radioactive decay of carbon-14 through hundreds of generations.

Doses to the whole-body and reproductive cells were averaged, weighted according to population; bone and thyroid doses were averaged over that portion of the population who were infants at the time of highest concentrations of relevant radioisotopes in the diet. Average doses to older children and adults, and thus to the total population, were smaller. Some local averages, particularly in the case of the thyroid, were much higher.

All one year doses are for the year, within the period covered, in which the highest yearly doses were received. The highest one-year doses to the whole-body and skeleton from tests prior to 1961 were experienced in 1958-1959. The highest one-year doses to the whole-body and to the skeleton from the 1961 tests are expected during 1962 and 1963.

TABLE I

Estimated Radiation Doses in the United States

(Doses expressed in millirem)

Tissue or organ	From all tests through 1961	From natural background	FRC Radiation Protection Guides* for normal peacetime operations Population groups
Whole body			
1 Year	10- 25	100	170
30 Years	60-130	3,000	5,000
70 Years	70-150	7,000	11,900
Reproductive cells			
1 Year	10- 25	100	170
30 Years	60-130	3,000	5,000
70 Years	70-150	7,000	11,900
Bone			
1 Year	30- 80	130	500
70 Years	400-900	9,100	35,000
Bone marrow			
1 Year	20- 40	100	170
70 Years	150-350	7,000	11,900

*The Radiation Protection Guide for whole-body exposure of individual radiation workers is 5,000 millirems per year.

APPENDIX "B"

DISCUSSION OF THE NUMERICAL VALUES IN TABLES II AND III

The estimates of genetic effect are based largely on the reports of the Committee on Genetic Effects of the National Academy of Sciences, contained in the Academy's 1956 and 1960 Summary Reports on the Biological Effects of Atomic Radiation. The Summary Reports concluded from the available scientific information that the genetic effects of exposure of a population to small doses of radiation are proportional to the average dose to the reproductive cells of potential parents.

The Committee reported that normally some four to five percent of children born have or will develop a severe physical or mental defect. Of these defective children about half, or two percent of the total number born, are thought to have traits whose frequency in the population is directly dependent on the mutation rate.

The Academy Committee utilized data on mutation rates in mice and estimated the effects on human populations, assuming that human radiation-induced mutation rates are the same as in mice. The 1956 Report estimated that if the parents of the present generation were exposed to 10,000 millirems, this average dose would give rise to some 50,000 additional defective children among 100 million children born. The total number for all future generations, assuming no change in the size of population, was estimated as 500,000.

Recent data have shown that radiation given at a very low rate produces fewer mutations than the same total dose given quickly. Since the earlier estimates were based on high dose rates, they should be reduced accordingly. The results from recent experiments with mice indicate that when both parents are irradiated the best estimate of the number of mutations should be only 1/6 as large as with high dose rates.

An application of these modified estimates to the reproductive cell exposures estimated to occur from past weapons tests, approximately 100 millirems over the first 30 years, leads to an estimate of 110 cases of serious inherited defects in the first generation of 130 million births. The estimates of radiation doses in Table I apply only to radiation received by the present population of the United States.

At least four physical phenomena contribute to making the radiation doses to future generations from these tests much smaller. In fact, in a few decades the exposure per generation from residual radioactivity produced by these tests will have dropped to less than one percent of the exposure to the current population.

In the case of the whole-body and reproductive cells, about 50% of the 30-year dose from tests through 1961 has resulted from exposure to radiation from relatively short-live gamma-emitting materials outside the body. As a result of radioactive decay, these will have essentially disappeared within a few years.

It is estimated that about 20 percent of the 30-year dose is from cesium-137 in the diet. Most of this results from the direct deposition of fallout on vegetation. When the deposition rate is low, the availablility of cesium-137 is small. This factor, together with its short retention time in the body, makes this radioisotope a small contributor to internal irradiation. About 25 percent of the 30 year dose is due to cesium-137 outside the body. The dose rate from this source decreases with time, not only as a result of radioactive decay with a half-life of 27 years, but also because of decreasing availability due to migration into the earth or into streams, storm drains, etc. The dose rate from this isotope may be reduced by 1/2 to 1/10 after 30 years in addition to radioactive decay.

It is estimated that carbon-14 resulting from tests through 1961 will produce a radiation dose of 10 to 15 millirems in the first 30 years, about 10 percent of the 30 year genetic dose from fallout to the present population. The radiation dose rate, after equilibrium with the oceans has been reached, will be about 0.025 millirem per year, or 0.75 millirem per generation. Although the dose rate is very small, it is of interest because it will continue at a rate which decreases with the radioactive decay of carbon-14 through hundreds of generations.

In addition to its radiation effects, carbon-14 may produce mutations through disruption of the normal chemical structure of the gene when the atom of carbon-14 is converted into nitrogen. The contribution from this effect appears to be small in comparison to the radiation effect, and is too speculative to provide a firm basis for numerical estimates.

The current total incidence of deaths due to leukemia in the United States is about 12,000 per year and that of bone cancer is about 2,000 per year. These amount to average rates for all ages of 7 cases per one-hundred thousand persons and 1.1 cases per one-hundred thousand persons, respectively.

It is assumed that the incidence of these diseases as a result of exposure of the blood-forming tissues and the bone, respectively, to radiation is proportional to the exposure. Observations of number of cases of leukemia resulting from very large doses of radiation suggest that up to ten percent of the normal incidence of leukemia may be due to exposure to radiation from natural sources, amounting to an average of 7,000 millirems in 70 years. The same assumption has sometimes been made for bone cancer. These assumptions were made, for example, by the United Nations Scientific Committee on the Effects of Atomic Radiation (1958) in estimating an upper limit to the number of cases of leukemia and bone cancer that might be expected from low levels of exposure such as those from fallout from the testing of nuclear weapons.

On this basis, one could estimate that if an average lifetime exposure of 7,000 millirems to the blood-forming tissues of the population of the United States results in a total of about 84,000 cases of leukemia in the period of an average lifespan of 70 years, the average lifetime exposure to fallout could be expected to result in a total of up to 2,000 cases of leukemia, averaging about 30 per year. The average exposure to the population as a whole from fallout is estimated to be about 175 millirems to the bone marrow, about half the value calculated for infants, as shown in Table I. A corresponding estimate for the number of cases of bone cancer from a population weighted lifetime dose of about 450 millirems would give an upper limit of 700 cases in 70 years, averaging about 10 cases per year.

For comparison, there are about 1,700,000 deaths each year in the United States from all causes. Of these, up to about 1,400, or about 10% of the total due to leukemia and bone cancer from all causes, are attributed to radiation exposure from natural sources. The possible additional 40 deaths from these causes, as estimated above, illustrate the degree of risk to an individual from fallout in comparison to risks already present.

TABLE II

Effect of Fallout on the Number of Gross Physical or Mental Defects in Future Generations in the United States

(No allowance has been made for future increases in population)

(1) Estimated number of cases due to all causes (hereditary and non-hereditary) in children of persons now living	(2) Estimated number of additional cases in the first generation (children of persons now alive) caused by all tests through 1961		(3) Estimated total number for all future generations from all tests through 1961		(4) Risk to an individual of the next generation from all tests through 1961
	Fallout	Carbon-14	Fallout	Carbon-14	
4,000,000-6,000,000	100 Range (20-500)	10 (2-50)	1,000 (200-5,000)	2,000 (400-10,000)	1/1,000,000

The upper figures in columns 2 and 3 are best estimates based on radiation-induced mutation rates in mice, and on the spontaneous incidence of these defects in man.

The lower sets of figures represent the range within which the true value may reasonably be expected to lie.

TABLE III

Certain Malignant Diseases in the Next Seventy Years in the United States

	Estimated total number of cases from all causes (present incidence)	Estimated number of cases caused by natural radiation	Estimated number of additional cases from all tests through 1961	Risk to an individual of developing the disease due to all tests through 1961
Leukemia............................	840,000	0-84,000	0-2,000	0-1/100,000
Bone Cancer	140,000	0-14,000	0-700	0-1/300,000

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FOR IMMEDIATE RELEASE

Fallout file

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Sanford Gottlieb, LI 6-4859

A University of Minnesota physiologist said today that there are two important facts about fallout which Senators, now debating the nuclear test-ban treaty, "can ignore only at the risk of great damage to the people of the United States and the world." Dr. Maurice B. Visscher defined these facts as: (1) "good scientific evidence" that radiation at the average levels already produced by fallout from nuclear bomb testing is capable of increasing the incidence of cancer by significant amounts, and (2) fallout is not uniform and, as a consequence, whole population groups hundreds of miles from the site of an explosion "have had at least 18 times as much exposure as did the average" in the state of Utah.

The statement was released by the National Committee for a SANE Nuclear Policy (SANE) in Washington. Dr. Visscher, who has been a Professor of Physiology at the University of Minnesota since 1936, is a member of the sponsoring board of SANE. He is a former president of the American Physiological Society and former chairman of the AMA's Section on Pathology and Physiology.

The full text of Dr. Visscher's statement follows:

incidence in children born to mothers who had pelvic X-rays during pregnancy can be used to calculate the probable effects of radiation from fallout. He shows that five-to-ten per cent increase in childhood cancer mortality is likely from radiation due to the 1961-62 series of tests. This would mean an addition of 100 to 200 childhood deaths per year from cancer in the United States alone. Calculated for the world population of children the added deaths in this category would be at least 2,000. In addition there would be the genetic defects, for which adequate data for calculation of added risk do not exist, but almost no one doubts that a real addition to prior risk has occurred.

It seems especially likely that the addition of Carbon-14 which occurs with fusion as well as with fission bombs, will inevitably increase the incidence of chromosome damage since that element becomes incorporated in the chemical structure of the chromosome and would disrupt the structure at the time of its decay to another element.

One may choose to call the suffering and death of a few thousand children and the psychic trauma to their relatives and friends a necessary sacrifice to world security, but one cannot in good conscience ignore the scientific evidence which indicates it to be a probability of high order. Not only is there good evidence that increased radiation at the levels to which the average person in the U. S. has been exposed as a result of bomb-testing produces an increased incidence of cancer and leukemia, but of perhaps even more importance is the fact that fallout is notoriously irregular in its pattern of deposition. There are many examples of this fact, but the 1962 Nevada tests provide a good example.

The August 16, 1963 issue of Science carries a report by Pendleton, Lloyd and Mays on the Iodine-131 exposure of the population of Utah as a result of the U. S. test series in 1962. The authors of the report measured the Iodine-131 content of milk from 39 stations in the state, and found evidence that the resulting exposure of the thyroid glands of young children in Utah would be one rad, on the average, and 14 times as much in the area of the state in which the highest values were found. The current radiation standards fix 0.5 rad per year for the general population as the level at which protective measures should be undertaken.

Radioactive fallout does not distribute itself evenly over the entire country. Weather and wind conditions at the time of the explosions are usually such that the spread of fallout is uneven, sometimes extremely so, even at great distances from the site of a detonation. Other factors such as soil and feed conditions also enter into the picture. For example in Minnesota the State Board of Health has measured Strontium-90 values in milk in various parts of the state for two years and the findings show values ranging from 5 to 50 micromicrocuries per liter of milk from different sections. The same type of variations occur in the case of wheat and other foodstuffs. A mean or average value for the country is a pure fiction for persons who happen to live where levels are high. We may very possibly find ten or twenty years from now, that many people will be dying from bone cancer due to Strontium-90 in those areas of the country in which fallout has been greatest and in which weather and crop conditions are such as to put the largest amounts of Strontium-90 in the food we are feeding our children today.

Thus there are two very important facts which the United States Senate can ignore only at the risk of great damage to the people of the United States and the world. They are, first, that there is now good scientific evidence that radiation at the average levels already produced by fallout from bomb-testing is capable of increasing cancer incidence by significant amounts, and, second, that fallout is not uniform and, as a consequence, whole population groups hundreds of miles from the site of an explosion have had at least 18 times as much exposure as did the average in the state of Utah. The average figures for radiation exposure may look small but there are unquestionably individuals whose exposure has been a hundred or more times the average.

It is not irrelevant to ask whether, if nations continue adding to the radiation load in the environment by bomb-testing, they should not be held legally and financially as well as morally liable for the damage they do. Indefinite continuation of bomb-testing in the atmosphere will, with a probability of thousands to one, cause disease, death, and genetic damage to many persons. If the U. S. Senate fails to ratify the test cessation agreement, those members of that body who vote against ratification will be voting to cause great human damage. They should realize that they are making the United States morally responsible for untold human suffering. In all justice the United States should also be held financially responsible for the damage it will do if it continues its testing program and contaminates the environment for its own and other peoples of the world with additional radiation.

[1964]

Nuclear Weapons

SENATOR GOLDWATER SPEAKS FOR HIMSELF:

"I hope the administration will call for an immediate resumption of the nuclear tests. Frankly I do not care what the rest of the world thinks of us."

(Congressional Record, Vol. 107, page 17340, Aug. 29, 1961)

"Some day, I am convinced, there will either be a war or we'll be subjugated without war ... real nuclear war... I don't see how it can be avoided -- perhaps five, ten years from now."

(New York Post, May 8, 1961)

On Russian nuclear weapons test resumption in 1962 in the Pacific:
"Let them do it. We'll just test a bigger one."

(Phoenix Gazette, Apr. 26, 1962)

On knocking down the Berlin Wall:
"We can allow ourselves this firmness because of superiority in weapons and atomic bombs."

(Washington Star, Nov. 3, 1963)

On the 1963 Test Ban Treaty:
"Every responsible member of the Government knows full well" that the treaty "envisions a non-aggression pact between the NATO nations and the military alliance of the Soviet empire, the Warsaw Pact nations."

(Speech in Madison, Wisconsin, Aug. 17, 1963)

"I'd drop a low-yield atomic bomb on Chinese supply lines in North Vietnam."

(Newsweek, May 20, 1963)

"I have suggested, along with many responsible leaders who have considered the problem, that a way must be developed to provide NATO with its own stock of small, tactical, nuclear battlefield weapons -- what may be truly called conventional nuclear weapons.

"I am convinced, for instance, that the majority of the great Americans who have commanded NATO would agree that NATO's effectiveness would be enhanced if a political solution for the control of these small conventional nuclear weapons could be worked out in NATO itself."

(Speech to Convention of Veterans of Foreign Wars, Cleveland, Ohio, Aug. 25, 1964)

"Q. Do you also still advocate helping possible uprising in Eastern Europe by being prepared to move a task force equipped with the appropriate nuclear weapons, along with an ultimatum?

"A. If that became necessary, if that were the only way, yes. For example, go back to Hungary. Had the United States followed through her commitments to Hungary, I think Hungary would be a free country today. These are tools that we have to be ready to use if we're going to be able to say to people: If you're willing to fight for freedom, we're willing to help you."

(Editors News Service, July 10, 1964, quoted from Der Spiegel, June 29, 1964)

"Q. But haven't you advocated the use of nuclear weapons in South Vietnam to defoliate the jungle? Would that be a realistic policy?

"A. About a month-and-a-half ago on a television show I was asked a technical question, how could you get at the trails through the rain forests of North Vietnam.

"Well, I served in the rain forests of Burma and I know that the only practical way to get at them is defoliation so an answer to a technical question like this -- one possible way of doing it even though I made clear this would never be done, would be the use of low-yield nuclear devices."

(New York Times, July 9, 1964, quoted from Der Spiegel interview, June 29, 1964)

"Whatever touches on the question of reducing troops in Europe, I believe can only be considered when our NATO allies possess tactical atomic weapons, and also are justified to use them."

(Welt am Sonntag interview, Nov. 3, 1963)

"...NATO...is drifting in disuse and disarray because of a lack of leadership. The key problem is whether we will trust our NATO allies more than we trust our Communist enemies.

"Actually, the only way to prevent the proliferation of national deterrent forces would be to provide NATO itself with a nuclear force under NATO's own control... As it stands, however, the administration -- in order to placate the Soviets -- is obviously pushing for a neutralized Europe, a nuclear-free Europe.

"...it is better to make concessions to our allies than to any enemy sworn to bury us.

"...I suggest, they (allies) are entirely correct when they question our tendency for seeking accommodations with communism through bilateral negotiations.

"Our government appears to be so preoccupied with reaching points of accommodation with the Communists that it doesn't have time for more constructive and realistic relations with our friends."

(Goldwater column, Los Angeles Times, Jan. 23, 1964)

On strengthening Germany:
"Yes. In fact, I'll say this -- not because you're here in the interest of a German magazine -- that I think the peace of the world depends upon a large measure to a constant alliance between our country and Germany. I think we have to work -- although I can't suggest any route -- to a united Germany. This is the one deterrent that has always worked against Russia. An alliance with Germany I think is imperative. I think two wars have demonstrated it. And I say this with all due respect to our military: Had not Germany in both wars been subjected to the supreme command of men -- or a man in any case -- who didn't understand war, I think Germany would have won both of them."

(Should nuclear weapons then be given to Germany?)
"No. Not the German army or the French army or the Italian army. These should be weapons for NATO and there'd still have to be some measure of control. But that control ought to be vested as closely as possible in NATO itself... We're talking about tactical nuclear weapons of a very small nature. We're talking of effects, I would say, mostly under the 1,000-ton capability. The only advantage of these weapons over the conventional weapons of the same size is the ease of delivery, and I would say that in these cases the Supreme Commander should be given great leeway in the decision to use them or not use them."

(Washington Star, July 10, 1964, quoted from Der Spiegel interview, June 29, 1964)

The Los Angeles Times

"DR. STRANGEWATER: OR, HOW I LEARNED TO LIVE WITH AND LOVE THE BOMB"

Speech Files: Speech Material
SD-Nuclear Wpns

COPY (Sf)

October 5, 1964

Professor Walter Selove
520 Brookview Lane
Havertown, Pennsylvania

Dear Professor Selove:

Thank you so much for your material on "Nuclear Weapons: Who Should Control Them?"

This material will be most helpful to me in the campaign.

Best wishes.

Sincerely,

Hubert H. Humphrey

520 Brookview Lane
Havertown, Pa.
September 20, 1964

JD

RECEIVED
SEP 23 1964

Senator Hubert H. Humphrey
Senate Office Building
Washington D.C.

Dear Senator Humphrey:

I am enclosing for your information a copy of some remarks I prepared for a local Democratic meeting, on "Nuclear Weapons: Who Should Control Them?" Although these remarks were for verbal delivery, and would not read too well in print, I would be happy if you wished to draw on any of this material for use in the campaign.

With most warm regards and appreciation,

Walter Selove

Walter Selove
(Professor of Physics, University of Pennsylvania)

(Copy to President Johnson)

Remarks by Walter Selove -- September 15, 1964

NUCLEAR WEAPONS : WHO SHOULD CONTROL THEM?

I think that you will not generally find scientists taking an active part in a political campaign. But this is no ordinary campaign. Sen. Goldwater is dead wrong about a host of important things. I wish in particular to speak about his expressed views on control of nuclear weapons -- views which are highly dangerous and completely unsupportable.

First, let me make clear -- I am not a pacifist. I have worked in the nuclear weapons laboratory at Livermore. There was a time when a strong case could be made for building up the xxx nuclear weapons force of this country. But that time has passed. We have enough -- far more than enough. Senator Goldwater has said that the test-ban treaty was written "in favor of our xxxxxx enemies." What he seems unable to understand is that the test-ban agreement was an important measure which benefits both the U. S. and the Soviet Union. How is it that in fact we can both benefit? The answer is important, and it bears on the main question I want to discuss -- the question: who should control nuclear weapons?

Senator Goldwater says that "small" nuclear weapons should be usable at the discretion of military commanders. Even so, he has retreated considerably from his first, quite blanket, proposal for such dispersal of control. The argument was given, first, that these weapons were, after all, not so large, and that the field commander should be free to use them against any military targets. Under severe criticism, the Senato retreated to the position that the NATO commander, and not any lower officers, should have this freedom --"great leeway in the decision", he said. But still this stand frightens many people, as it should. It is not clear, but the Senator appears now to be possibly retreating to the position that even the Supreme Nato Commander should only be free to use nuclear weapons fmx in retaliation for their use first by an attacker.

Now, a policy to allow military commanders to initiate the use of nuclear weapons under any circumstances where the President is alive is dangerous, unjustifiable, and unnecessary. It is the President who has the Hot Line to Moscow, and who can determine whether an accident or a mistake has occurred, before loosing these terrible devices--- it is not the NATO commander, and certainly not the field commanders.

Are mmx we really in great danger of being overwhelmed by a massive surprise attack by the Soviet Union, in Europe? Must we be prepared to retaliate instantly -- without waiting even one or two hours to determine the actual facts? Does our security depend upon being prepared to use nuclear weapons <u>instantly</u>, in any circumstances other than large scale nuclear attack directly on the U.S. or on its Allies?

No. The answer to all of these questions is <u>no</u>. Our only real security is in the sane behavior of the Soviet Union -- the sane behavior of those Soviet leaders who control Russia's nuclear weapons. If those leaders were to go insane, nothing could save us from enormous destruction. It may be consolation to some that if Russia were to attack us then 100 million Russians would also die, in the first hour -- but our ability to inflict that terrible damage does not constitute a "defense". There is no defense against massive nuclear attack. There is no defense for us -- and none for Russia. There is no defense now; and the best scientific and engineering minds in this country do not see any defense in the foreseeable future, meaning 10 years at least.

No one can guarantee that some new physical principle may not be found, which will help produce great attrition in an attack. But the power of modern weapons is such that only one large bomb, exploded near Philadelphia, could set everything afire from Trenton to Wilmington. Three or four such bombs would completely destroy the East Coast from New York to Washington. And these bombs could be fired from ships so as to arrive on target only a few minutes after launch. The problem of interception -- and essentially 100% interception under massive attack is needed, -- cannot be solved, by any method now considered.

If our only real security rests on the rational behavior of the Russians (and on the rational behavior of our own leaders, let me add!), then our strongest interest lies in searching out measures of mutual interest, and in searching out and nurturing all evidences of sane behavior, by the nuclear giants. It would be mad for either side to initiate the use of nuclear weapons in ~~xgx~~ anger, <u>or to attack the other side in a way which would compel nuclear retaliation</u>. Let's face it. If either side's leaders go crazy, we are all lost. If we have any chance of coming safely through this present period of balance of terror, it lies in cultivating human understanding on both sides, not in either side provoking the adversary to the point of explosion.

Lyndon Johnson and Hubert Humphrey speak for all of us, and for all sane men, when they insist that the President have absolute control of these unprecedented weapons. ("Conventional" nuclear weapons?-- incredible term!) The smallest nuclear weapon carries the danger of the largest -- once the first one is set off, there is no logical stopping place in an escalating series of larger and larger blasts. Senator Goldwater may not understand this. To him the world may be a simple place, where you need only be tough and the other guy will roll over and play dead. Well -- if you believe, like me, that the world may not be a safe place but promiscuous use of nuclear weapons won't make it any safer, then let me urge you to go out and work your head off-- carry this message to every door. Barry Goldwater does not understand nuclear weapons, just as he does not understand human beings. He simply does not have the sense to be allowed to be President. <u>Let's keep him out!</u>

major attack.

A main point here: Saturation attack by an enemy, or a saturation response by us, is not defensible. If nations want safety, they had better agree to verified and inspected cut-backs. As President Kennedy said: increase in power equals increase in peril.

4. What About Putting Atomic Weapons in Space-Orbiting Vehicles?

- - we have an agreement with Russia not to do this. A safe enough agreement yet, because it isn't practicable militarily to use space vehicles this way. E.g. Technology of re-entry with precision of when and where for a bomb from a space-craft still too complicated.

- - Meanwhile we have made headway toward getting a detection system in space:

    a. Just put the biggest payload in orbit ever—thus pulling even or ahead of Russia in rocket thrust.

    b. This is prelude to our MOL (Manned Orbiting Laboratory) which among other things could be a space policeman.

5. What is our Strategic Theory and Capability to Deter Attack, if once one is made, it is indefensible?

A. Conventional arms:

- - we have trebled our personnel and equipment capacity to fight small, or brush-fire wars. (since 1961 done this)

- - Operation Big Lift in Europe, a like enterprise to come in Far East, and more plans developing—designed to fast maneuverability to any part of world, independent of foreign bases.

- - this gives more options of choice in containing small wars, and opportunities other than doing nothing, or massive retaliatin

B. Nuclear weaponry: TACTICAL and STRATEGIC

-- have far greater diversity and sophisticated tactical weapons development than Russia. Useful in containing superior ground forces still within context of "limited" war. An "escalation control" factor.

-- have a capacity to absorb a major first strike with strategic weapons, and retaliate to point of total enemy destruction if necessary.

This knowledge has been made "credible" and is therefore a deterrent to an aggressor's ideas of striking first.

-- in number of strategic weapons, degree hardened and dispersed, land based, sub based, surfaceship based, we have generous superiority.

6. How reliable are our missiles?

Main point here: Mr. Goldwater has confused the reliability of a missile with the reliability of a system.

-- Any weapon from a pistol on up can misfire or suffer from some other mechanical failure to achieve objective.

-- For any strategic weapon a reliability factor is calculated with precision.

It may be as low as only 50%. BUT

If its target is only moderately important, two missiles may be zeroed on it--raising reliability of system to 75%. If target is highly important, 3,4 or 5 weapons may be targeted upon it. The reliability of the system to target never reaches 100%, but it can be statistically computed to high reliability.

We have a high degree of security, which is being improved constan ly. for our technology is not standing still in improving the reliability of both individual weapons and the system.

On the other side of the coin: this multiplication of weaponry on single targets is not designed to "overkill" anybody. It is designed for the reliability of a retaliatory system. It is necessary to that reliability.

Hence-- critics from both left and right miss the point of our strategic weapons system and tend to cancel one another out in their conflicting charges.

Worse--both seem to be deliberately misunderstanding, for neither group ever makes any effort to recognize the stated theory of our strategy and to evaluate it in terms of what it is built for.

This is not constructive political, military, or scientific criticism. This is shabby politics with national defense and with issue of peace itself, insofar as nuclear deterrence can give it.

Fortunately: Mr. Khruschev knows better, even if Mr. Goldwater does not.

7. <u>Can an enemy first-strike with high megatonnage create an electro-magnetic disurbance, such as to "fuse" our control systems?</u>

-- We are not sure--but neither can the Russians be.

-- In any case the liklihood of their doing it to <u>all</u> of our dispersed retaliatory system is highly unlikely.

-- SO --this argument amounts to taking an outside theoretical loophole and converting it to a dire threat.

AND therefore is an irresponsibility especially when more manned bombers or more atmospheric testing would <u>not</u> be germane to finding a protective answer.

-- MEANWHILE --we are "hardening" our electronic systems as well as our missiles.

John Stewart

File

Nuclear Weapons

TO FGD ~~10/8/64~~

From Louise Alport Lise

RE: Nixon - No public announcement of contingent nuclear authority in Eisenhower Administration!

Nixon has been getting his only wire coverage with his repeated:

--- demanding LBJ tell the public who has nuclear authority if...

--- demanding a public debate on who should have it between LBJ/Goldwater

--- saying (with his full authority as former Eisenhower Vice President) that the public has a right to know...that LBJ's lack of response shows he's covering up something.

IN FACT:

DURING THE 8 EISENHOWER-NIXON YEARS THE CONTINGENT NUCLEAR AUTHORITY WAS NEVER ANNOUNCED PUBLICLY NOR, WHEN ASKED, DID PRESIDENT EISENHOWER TELL THE PUBLIC. (See attached press conferences)

(George Bunn, Arms Control -- did a search)

How about that!

10/8/64

NIXON CHALLENGES ATOM-ARM STAND

Calls President 'Demagogue' on NATO Weapons Issue

CHICAGO, Oct. 7 (UPI) — Richard M. Nixon accused President Johnson today of "political demagoguery" and "irresponsibility" in his dispute with Senator Barry Goldwater over the use of nuclear weapons.

Mr. Nixon proposed that the President and the Republican Presidential candidate confront each other in a public debate, possibly on television, on the issue of whether the commander of the North Atlantic Treaty Organization should ever have authority to unleash nuclear weapons.

The former Vice President, stumping the Midwest for Mr. Goldwater and other Republican candidates, addressed a gathering of Cook County precinct captains here. Earlier he spoke at Mattoon and Aurora, Ill.

"President Johnson's attack on Senator Goldwater on the NATO nuclear weapons issue is political demagoguery at its worst," Mr. Nixon said, continuing:

"It is Johnson's, not Goldwater's, position on this issue which is reckless and irresponsible.

"There are 26 NATO divisions, including six American divisions, in Europe. They face over 100 Communist divisions. Our NATO divisions would be at a terrible disadvantage except for the fact they are equipped with battlefield atomic weapons."

He said Communist troops were aware of this and the knowledge had kept the peace between Eastern and Western Europe. Then he declared:

"Responsibility for authorizing the use of atomic weapons rests solely with the President of the United States."

"There is no difference of opinion here. Senator Goldwater's position, as set forth in the McElroy task force report, is that the President should continue to have this sole responsibility.

"But President Eisenhower recognized that in the event of a Communist attack in Europe, a delay of even a few minutes might result not only in losing the war, but would endanger the lives of 250,000 American fighting men stationed in Europe.

"He consequently provided that if a Communist attack occurred and the President was unable to issue the order for response with battlefield atomic weapons, because of a communication breakdown, illness or other reasons, that power under certain carefully defined circumstances could be exercised by the NATO commander.

"President Eisenhower had a particularly strong feeling that this procedure was wise and necessary because of his three illnesses in which there were periods when he would not have been able to issue an order for the use of atomic weapons.

"President Johnson has charged that Senator Goldwater in calling for a return to the Eisenhower policy is 'trigger happy, and a warmonger.' The people of America and particularly the 250,000 American fighting men in Europe are entitled to have these questions answered by President Johnson immediately."

Earlier, Mr. Nixon told a news conference in Chicago that South Vietnam might be lost within a year and all of Southwest Asia within three years if United States policies were not changed.

"The choice here is either winning the war in South Vietnam or fighting a much bigger one in Southeast Asia," he said.

"Now is the time," he added, "to halt creeping Communist aggression."

Final Registration For Election Opens At Polling Stations

Extensive voter registration drives by Democrats and labor, civic and social welfare organizations began to show results last night as registration began at nearly 5,000 polling places here.

Early last night, the Board of Elections reported lines had formed at a number of polling places in the city. But an official said that it was too early to predict the number of registrants. He said that many per-

A40N HX

NIGHT LEAD NIXON

BY LOUIS A. PANARALE

UNITED PRESS INTERNATIONAL

CHICAGO, OCT. 7 (UPI)--RICHARD M. NIXON WARNED TODAY THAT SOUTH VIET NAM MAY BE LOST WITHIN A YEAR AND ALL OF SOUTHEAST ASIA WITHIN THREE YEARS IF UNITED STATES POLICIES THERE ARE NOT CHANGED.

"THERE IS NO WAY OUT OF THIS MESS IN VIET NAM UNLESS THERE ARE STRATEGIC CHANGES," THE FORMER VICE PRESIDENT SAID.

NIXON, STUMPING THE MIDWEST IN A HARD-DRIVING CAMPAIGN FOR THE REPUBLICAN STANDARD-BEARERS AND OTHER GOP CANDIDATES, TOLD A NEWS CONFERENCE IN CHICAGO THAT THE UNITED STATES SHOULD CUT OFF COMMUNIST SUPPLY LINES IN NORTH VIET NAM.

IF THE ADMINISTRATION'S PRESENT POLICIES AREN'T CHANGED, NIXON SAID "WITHIN A YEAR, VIET NAM MAY BE LOST. AND IF THE BALANCE OF SOUTHEAST ASIA MAY BE LOST WITHIN THREE YEARS."

"THE CHOICE HERE IS EITHER WINNING THE WAR IN SOUTH VIET NAM OR FIGHTING A MUCH BIGGER ONE IN SOUTHEAST ASIA," HE SAID.

FROM CHICAGO NIXON HEADED TO MATTOON, ILL. HE ALSO SCHEDULED AN ADDRESS AT A PARTY RALLY IN AURORA, ILL., AND A NIGHT MEETING WITH GOP PRECINCT CAPTAINS IN CHICAGO.

NIXON PROPOSED THAT PRESIDENT JOHNSON AND REPUBLICAN PRESIDENTIAL CANDIDATE BARRY GOLDWATER "CONFRONT EACH OTHER" IN A PUBLIC DEBATE ON THE ISSUE OF WHETHER THE NATO COMMANDER SHOULD HAVE AUTHORITY TO TRIGGER NUCLEAR WEAPONS.

NIXON SAID THE REPUBLICAN STANDARD-BEARER'S OPPONENTS HAD DISTORTED HIS VIEWS AND "THE 'TRIGGER-HAPPY' LABEL HAS BEEN GIVEN TO GOLDWATER BY JOHNSON AND HATCHET MEN OF THE DEMOCRATIC PARTY."

"SENATOR GOLDWATER SAID THAT IN THE EVENT OF A COMMUNICATION BREAKDOWN OR ILLNESS BY THE PRESIDENT, THE NATO COMMANDER SHOULD HAVE THE RIGHT TO CONTROL THE NUCLEAR FORCE," NIXON SAID.

NIXON SAID FORMER PRESIDENT EISENHOWER FOLLOWED THE POLICY ADVOCATED BY GOLDWATER.

"I THINK IT SHOULD BE EXPLAINED BY PRESIDENT JOHNSON JUST WHERE HE STANDS ON THIS MATTER," NIXON SAID. "AFTER ALL, IT IS PRESIDENT JOHNSON WHO WISHES TO CHANGE THE PROCEDURE. THE PRESIDENT SHOULD REASSURE THE AMERICAN PEOPLE ON THIS ISSUE....

"I WOULD SUGGEST THAT THE BEST WAY TO SETTLE THE ISSUE IS FOR THE TWO MEN TO CONFRONT EACH OTHER BEFORE THE NEWS MEDIA."

NIXON SUGGESTED A "DEBATE," POSSIBLY ON TELEVISION IF IT COULD BE ARRANGED.

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"UT LEAD PEGGY

EISENHOWER, AS QUOTED IN AN INTERVIEW WITH THE AMERICAN BROADCASTING COMPANY AT THE REPUBLICAN CONVENTION, JULY 13, 1964.

. . . .

The President must be, of necessity, Commander-in-Chief. He is responsible for the conduct of our foreign relations and he is certainly responsible for giving all orders that pertain to every kind of emergency action once Congress declared war or war was thrust upon it as it was at Pearl Harbor.

Now, I think that some general statement that the Party reaffirms its--the supremacy or its faith in the supremacy of civil law and authority over the military and saying that they believe that the president is the only one that can authorize the use of any weapons...it's still the President's decision...

Edward T. Folliard. "Politics." Washington Post, October 7, 1964, p.A22

EISENHOWER'S NEWS CONFERENCE OF DECEMBER 2, 1959.

. . . .

Question. Merriman Smith, United Press International: Mr. President, in connection with your forthcoming trip, I would like to ask a slightly legalistic question.

Under law, you have the sole authority for the final determination of using nuclear or thermonuclear weapons in event of an emergency. Now, you will be quite some distance from the country during this trip. Have you made any arrangements or are such arrangements feasible where you leave such authority with someone in this country, or would you have to executite such a decision if it became necessary, overseas?

The President. No, there is no arrangement that puts the President's authority in anybody else. Such decisions that I have to make, though, are of such a character and are kept in such terminology that they can be executed from any position and by a simple message that could be delivered instantaneously.

Public Papers of the Presidents, 1959, p.786

EISENHOWER'S NEWS CONFERENCE OF JULY 8, 1959.

. . . .

Question. Mrs. May Craig, Portland (Maine) Press Herald: Mr. President, the laws say that only the President can order the release of nuclear bombs. I am told there is no provision for the President to delegate that power.

Do you think in the exigencies of modern war that there should be such an authorization? Do you think that your informal agreement with Mr. Nixon on assuming the Presidency if necessary carries the authorization to use nuclear bombs?

The President. Well, you sound to me a little bit like a lawyer, Mrs. Craig, because I'm not sure; I don't see how you could first of all deny any Commander in Chief, as a matter of fact, of exercising the responsibility for some delegation when it needs to be done. That's just his job, that's the way he would run things.

If in an emergency Mr. Nixon would succeed to my responsibilitiés, I would think that he would take them over in toto for whatever period he was there, and that there would be no reason for him not doing so. He would, in fact, be the acting President; and of course, in the case of a fatality, why then he'd be the permanent President.

So I think there would be no question about that at all.

<u>Public Papers of the Presidents, 1959</u>, p.510

[Aug. 27, 1964]

POSITION PAPER

SUBJECT: Decrease in U.S. Megatonnage

REFERENCES: Senator Goldwater's claims; Deputy Secretary of Defense Vance's speech 27 Aug., Cleveland, Ohio

1. Background -- Senator Goldwater has repeatedly claimed our defenses are getting weaker as a result of a deliberate decrease in our nuclear megatonnage. This line of reasoning seems to be that our ability to wage nuclear war is in direct ratio to our total megatonnage. It is the old "numbers game" and it is a false indicator of strength.

Deputy Secretary of Defense Vance replied to these assertions in a major defense policy speech in Cleveland on 27 August.

2. Facts -- In 1960 the United States had a large number of less efficient and hence obsolete nuclear war heads in our stockpile. These were the large blast type that had to be dropped from very high altitudes to avoid damage to our bombers dropping the bombs. As the Soviets increased their anti-aircraft defenses we had to modify our bombing tactics. Our shift was away from huge bombs from high altitude as we went to increased emphasis on low level attacks and use of missiles. This resulted in smaller bombs but more of them on a target. It was more efficient military use of nuclear explosives.

Thus, while mathematically the total megatonnage of our nuclear stockpile went down, our bombing effectiveness went up. This was important military progress.

Here is a key point: The shift from large "old fashioned" bombs to a larger number of smaller and more modern weapons did result in a large decrease in megatonnage of our stockpile. It did not result in a decrease in nuclear power of our armed forces. It did result in a "substantial" increase in the amount of destructive power the U.S. can place on enemy targets.

What was the attitude of the military leaders to the shift from obsolete large nuclear bombs to modern and smaller ones?

The Joint Chiefs of Staff recommended unanimously that the obsolete large bombs be eliminated and replaced by modern weapons (Vance speech, 27 Aug., Cleveland).

What was the position of the Eisenhower Administration on this issue? The recommendation of the Joint Chiefs of Staff was approved by Secretary of Defense Gates and by President Eisenhower in the summer of 1960 (Vance speech, 27 Aug., Cleveland).

3. Conclusions -- A. The claims of reduced megatonnage are essentially correct.

B. Such reduction does not mean a reduction in our nuclear warfare effectiveness. Actually, the reduction is the result of technicological advancements in nuclear weaponry, and means greater destructive power by the U.S. on enemy targets.

C. Senator Goldwater is playing the "numbers game." It is misleading and incorrect. He is urging, in effect, going back to the less efficient weapons of yesterday.

Unfortunately, the Russians wouldn't follow his advice, even if the U.S. did. What he is proposing, by supporting the obsolete weapons is the most dangerous form of unilateral disarmament. If he had his way, we would deny ourselves the advances of science in nuclear warfare. That really would be giving our fighting men and our nation second rate weapons.

D. The J.C.S. recommended shifting from old to new nuclear weapons -- resulting in an over-all megatonnage reduction -- but an increase in combat effectiveness. Republican Secretary of Defense Gates approved the JCS position.

Republican President Eisenhower approved it.

BUT NOT SENATOR GOLDWATER.

From the desk of MAX M. KAMPELMAN

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296-3300

9/14/64

John,

Here is another memorandum from General Hittle which could be useful.

MMK

File
Nuclear weapons

POSITION PAPER

SUBJECT: "Conventional" Nuclear Weapons.

REFERENCE: Goldwater statements; replies by Vance

1. Background -- Senator Goldwater has been trying to make a major issue out of giving field commanders power of decision on when to use small, or tactical, nuclear weapons.

He's been hit hard on this issue by the Administration spokesman, Dep. Secretary of Defense Vance, and by the press. He's tried, in return, to strengthen his position by shifting terminology and going the semantic route. In so doing he's put forward the term "conventional", in referring to the small or tactical A-weapons as contrasted with the large strategic bomb and missile war-heads.

A basic reference on Senator Goldwater's thinking on this matter of weapons control and classification of "small A-weapons" is his speech in Cleveland on August 25.

2. Discussion -- The key question seems to be this: Is Senator Goldwater's use of the term "Conventional" valid as applying it to the smaller nuclear weapons? The answer to that question is that it is NOT valid. Here's why -

1. The term "Conventional" has long been used, and still is used and accepted by the military and the press as applying to non-nuclear warfare and non-nuclear weapons. Thus, to try to justify the position he finds himself in, Senator Goldwater is using a non-nuclear definition to describe

nuclear weapons. This may be clever semantics, but it is not straight military thinking, and it is not right, either. He shouldn't be able to get out of this hole he's dug himself into on this issue by merely switching labels.

2. One of the key reasons basic control of nuclear weapons has been retained by the president as commander-in-chief and as chief of state is that the decision to use ANY nuclear weapons is a policy decision of the highest order. Once <u>any</u> nuclear weapons are used, then the whole nature of the conflict changes. It is the <u>kind</u> of weapon in this case that matters. Once <u>any</u> nuclear weapon is used, then the shift has been made to a different kind of war than that which is called "conventional" - the kind of war that doesn't use nuclear weapons. What does the change to nuclear weapons involve? Many things; for instance: larger blasts than any conventional explosive; fall-out, not only on the battlefield, but also beyond the area of immediate fighting, -- and what fighting in Europe, or anywhere, won't take place in some cities and villages? And this involves, in turn, fall-out on civilians. This has political implications of world-wide scope; Red propaganda would turn it against us throughout much of Asia where there is such sensitivity to nuclear war. It could seriously affect our relations with, for instance, Japan. Thus, a battle-field decision to use even a small nuclear weapon, would have international reverberations and results that would, possibly, far outweigh the temporary local gains

from the use of the weapon on the other side of the world. This, then, is a decision for the person charged with all U. S. military and foreign policy. That person is the president. It isn't a local commander responsible for a specific locality and preoccupied with the course of local conflict.

3. Escalation of non-nuclear (conventional) war would be bad enough. But escalation in nuclear war would be disaster for our nation and mankind. YOU CAN'T ESCALATE SOMETHING UNLESS YOU HAVE SOME-THING TO START ESCALATING FROM. THUS, THE USE OF THE FIRST NUCLEAR WEAPON GIVES THE BASE FOR ESCALATING INTO NUCLEAR WAR AND DESTRUCTION.

There is, frankly, division of opinion on whether or not a nation can engage in a little nuclear war. I don't think it's possible. Here's why: you start with nuclear weapons of battle-field size: both use the smallest, for example, a mortar shell, at the beginning. Then a commander who is in trouble uses a larger mortar shell; next there is local reason to use a cannon shell with a larger nuclear war-head. About this point the commander who is getting the worse of it decides that he'll use a small bomb (tactical, of course) for an air strike. Then the other commander calls for his small bombs; Pretty soon the one who feels he's losing will decide he needs large tactical bombs for a bigger enemy target. And, then, at that point does it move from "large tactical" to "small strategic" bombs and missils? No one can give a definite answer because no one knows that dividing line!

4. This matter of size of so-called small "conventional" battle-field nuclear weapons is a weak point of Senator Goldwater's argument. Probably the smallest is the equivalent of an explosion of 40 tons of TNT. This is, reportedly, the "Davey Crocket" battle-field sized burst. This isn't large by comparison with the super H-bombs. But it is large in terms of destructiveness. Let's remember that the huge Blockbusters of World War II were only a couple tons of TNT. So, even the smallest nuclear weapon is far beyond the normal scope of conventional warfare. Once it's used we've crossed the threshold of no return into nuclear war.

3. Proposal -- This is an issue raised by Senator Goldwater. He's wrong. It is about the only military issue that the public reacts to. It shouldn't be dropped, but used continually, both factually and emotionally.

4. Key Point -- In such a serious military issue he's shooting from the lip.