REPORT NO. 7

background material for the development of radiation protection standards

protective action guides for strontium-89, strotium-90 and cesium-137

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Staff Report of the

FEDERAL RADIATION COUNCIL

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TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

SUMMARY

This report provides information and guidance for actions appropriate to situations involving contamination of the environment by the radionuclides strontium-89, strontium-90, and cesium-137.Two conditions of environmental contamination have been examined: an acute localized contaminating event in which prompt action may be necessary to avoid the exposure that would otherwise result; and a widespread, generally increasing, low-level of contamination (from stratospheric fallout) that causes a continuous intake of radioactive materials by large numbers of people for a period of years. Special consideration has been given to the situation in the arctic region where, because of unusual ecological conditions and food chains, some population groups are exposed to levels higher than those in other parts of the United States.

In developing this report, the Staff of the Federal Radiation Council has had the assistance of an advisory committee from the National Academy of Sciences - National Research Council in regard to the biological effects from irradiation by strontium-89, strontium-90, and cesium-137; the assistance of an ad hoc panel of scientists to provide data on biological, chemical, and physical factors involving radioactive contamination of the environment; and a second panel to provide information on the dosimetry models related to these radionuclides.

The Acute Contaminating Event

The problem of evaluating when protective actions may be indicated following an acute contaminating event has been separated into three categories. Category I is limited to the transmission of radionuclides through pasture-cow-milk-man pathway. If pasture is contaminated the concentration of radionuclides in milk would build up rapidly, reach a maximum in about a week and then diminish by about half every two weeks as the result of weathering losses, new plant growth, and similar mechanisms. Protective actions initiated at approximately two weeks following the contaminating event will avert 50 percent of the projected intake; actions initiated at approximately 1 week following the event will avert 75 percent; and actions initiated within two days will avert 90 percent.

Category II is concerned with the transmission of radionuclides to man through dietary pathways other than that specified as Category I during the first year following an

acute contaminating event. This involves the use of feed crops for animals, including dairy cattle, and plant products used directly for human consumption. Immediate action to reduce the potential intake will not usually be required because of the normal delay in the use of such crops. However, an early decision will be required as to the need for examination of harvested crops to determine the degree of contamination before they enter normal marketing channels. Protective actions in Category II are not normally expected to be indicated unless action was first needed in Category I.

Category III is primarily concerned with the long-term transmission of strontium-90 through soil into plants in the years following a contaminating event. Residual contamination of cesium-137 may be a consideration for 1 to 2 years.

The benefits of a protective action taken in one category are largely independent of whether action is taken in another. The types of actions considered in the development of guidance in the report include:

1. Altering production, processing or distribution practices affecting the movement of radioactive contamination through the food chain and into the human body. This action may include storage of food supplies and animal feeds to allow for radioactive decay.

2. Diverting affected products to uses other than human consumption.

3. Condemning affected products.

The term "Protective Action Guide" has been defined as the projected absorbed dose to individuals in the general population that warrants protective action following a contaminating event; and a "protective action" as an action that will avert most of the exposure that would otherwise occur.

It is generally impossible to predict total doses solely from the degree of contamination of a particular crop. Therefore, the definition of protective action is extended in this report so that if the total projected dose from the use of all crops in Category II exceeds the Protective Action Guide, in order to make a substantial reduction in the total dose, action should be initiated against those crops that would make major contributions to that dose.

It is the purpose of the recommendations to discourage deliberate introduction of contaminated food into supplies of uncontaminated food as an acceptable solution to environmental contamination. Rather, it is recommended that if the contamination of a particular crop or dietary component is so high that it would not be acceptable for local use, the crop or dietary component not be considered acceptable for use in other areas to which it may be transported.

The recommended Protective Action Guides are:

For Category I: A mean dose of 10 rads in the first year to the bone marrow or whole body of individuals in the general population; and provided further that the total dose resulting from Category I not exceed 15 rads. For purposes of applying the guide, the total dose from strontium-89 and cesium-137 is assumed to be the same as the dose in the first year, whereas the total dose from strontium-90 is assumed to be 5 times the dose in the first year.

For Category II: A mean dose of 5 rads in the first year to the bone marrow or whole body of individuals in the general population. As an operational technique it is assumed that the guide will be met effectively if the average dose to a suitable sample of the population is one-third the PAG or approximately 3 rads for Category I and 2 rads for Category II.

For Category III: A Protective Action Guide is not recommended. Rather, if it appears that annual doses to the bone marrow of individuals may exceed 0.5 rad or 0.2 rad to a suitable sample of the population, such situations shall be appropriately evaluated.

Worldwide Contamination From Stratospheric Fallout

Studies of stratospheric fallout in the United States from past testing were reported in FRC Report Nos. 4 and 6. On the basis of this information, the Council concluded that the health risk from radioactivity in food over the next several years would be too small to justify protective actions to limit the intake of radionuclides either by diet modifications or by altering the normal distribution and use of foods, particularly milk and dairy products.

In Alaska, although the amount of fallout deposited per unit area is about one-fifth as much as that deposited in the 30° - 40° latitude band, a combination of ecological conditions and specific dietary habits of some Eskimos and Indians causes higher cesium body burdens than are found in the conterminous United States. Average body burdens of cesium-137 in these inhabitants were about three times as high in 1964 as they were in 1962. The estimated whole body doses to these individuals in 1964 ranged from about one–fourth to one–half of the numerical value of the Radiation Protection Guide (RPG) for individuals in the general population.

The practicality and value of protective actions against widespread environmental contamination from stratospheric fallout is limited because:

1. The condition to be alleviated is chronic exposure from long–term continuous intake (10 years or more).

2. A reduction in potential intake under these conditions requires basic changes in long–term agricultural practices, food processing practices, dietary habits, or all three.

3. The actions would have to be applied on a broad enough scale to reduce the average quantity of radionuclides in the total diet from foods produced throughout large areas or the entire country.

A Protective Action Guide is not recommended for this situation. Rather, annual doses from fallout equal to or greater than the numerical values of the RPG's can be used as an indication of when there is a need for a careful evaluation of fallout exposures.

In view of these considerations it is recommended that surveillance of the radionuclide content of food products contaminated with worldwide fallout be continued at levels appropriate to the situation. It is also recommended that surveillance and research programs examining the special ecological situations in the arctic region continue until future trends can be predicted with greater confidence.

SECTION I

INTRODUCTION

1.1 This background staff report provides information and guidance for actions appropriate to situations involving contamination of the environment by the radionuclides strontium-89, strontium-90, and cesium-137. In certain circumstances, such as the unforeseen or uncontrollable dispersal of large quantities of radioactive materials in the environment, the resulting exposure can be reduced only by protective actions taken against the radionuclides in the environment. In these circumstances, changes in the normal production, processing, distribution, and use of foods may be required.

1.2 FRC Report Nos. 1 and 2 provide radiation protection guidance for the control and regulation of the normal peacetime uses of nuclear technology in which control is exercised primarily on the design and use of the radiation source. The Radiation Protection Guides (RPG's) in those reports were developed as guidelines for the protection of radiation workers and the general public against exposures which might result from routine uses of ionizing radiation. In formulating those guides there was a judgment, or balance, between the possible risks associated with a particular radiation exposure and the reasons for allowing the exposure.

1.3 An important factor in providing guides for any purpose is the change in risk assigned to higher or lower doses and the corresponding effort to reduce them. Other factors influencing informed opinion of where and why a particular balance should be made include views regarding prevailing practices and the relative importance of health risks in relation to economic, political, or other considerations of national welfare. With respect to environmental levels of radioactivity, the RPG's reflect the residual risk considered acceptable after engineering and procedural controls have been applied at the source (i.e., place of origin) of the radioactivity to limit releases to the environment. The numerical values for these guides were placed as close to the annual dose from natural background radiation as technical, economic, and operational considerations allowed.

1.4 Although radiation doses numerically equal to the RPG's may impose a risk so small that they can be accepted each year for a lifetime if there is significant benefit from the programs causing the exposure, they do not and cannot establish a line that is safe on one side and unsafe on the other. Rather, some risk of injury may exist at any level of dose and the risk continuously increases with dose. Caution should be exercised in decisions to take protective actions in situations where projected doses are near the numerical values of the RPG's, since the biological risks are so low that the actions could have a net adverse rather than beneficial effect on the public well-being.

1.5 In contrast to the guidance given in FRC Report Nos. 1 and 2, FRC Report No. 5 provided general guidance for the protection of the population against exposure resulting from the accidental release, or from the unforeseen appearance, of radioactive materials in the environment. Specific guidance, including a numerical value for the Protective Action Guide (PAG), was provided for iodine-131. The PAG represents a consensus as to when, under the conditions considered most likely to occur, intervention is indicated to avoid radiation exposure that would otherwise result from transient environmental contamination. This consensus involves health, economic, sociologic and political factors for which the relative values are different than for the RPG. For the PAG these factors may include agricultural policies, the known feasibility of protective actions, related health impacts and similar considerations involved in the national interest.

Scope

1.6 This report provides background material used in the development of guidance for Federal agencies in planning activities to protect the population from strontium-89, strontium-90, and cesium-137 for certain situations in which these radionuclides may appear in the environment. A basic assumption in the development of the guidance is that a condition requiring protective action is unusual and should not be expected to occur frequently. Two conditions of environmental contamination have been examined: An acute localized contaminating event in which prompt action may be necessary to avoid the exposure that would otherwise result; and a widespread, generally increasing, low-level of contamination (from stratospheric fallout) that would cause a continuous intake of radioactive nuclides by large numbers of people for a period of years.

1.7 Exposure of the general population to radioactive materials in the environment may result from external irradiation, inhalation, and ingestion of such materials. For most environmental situations, ingestion will produce the greatest absorbed dose. Ingestion of radioactive materials may be limited by protective actions affecting the normal production, processing, distribution, and use of food. As in FRC Report No. 5, only ingestion is considered in the present report. Only the transmission pathway from pasture through fluid milk to man was considered important for iodine-131. In this report it is necessary to consider the additional routes through animal feed crops, human food crops, and root uptake due primarily to the longer radio-active half lives of the nuclides under consideration. The report also considers the situation in the arctic region where, because of unusual ecological conditions and food chains, some population groups are exposed to levels higher than those in other parts of the United States.

1.8 The numerical values of absorbed doses specified as guides for an acute contaminating event are not intended to authorize deliberate releases expected to result in absorbed doses of these magnitudes, nor do they have any relevance to civil defense applications.

Preparation of Staff Report

1.9 The staff reviewed the applicable literature on the biological aspects of exposure to the radionuclides of interest in this report. The literature included reports from such groups as the National Council on Radiation Protection and Measurements, International Commission on Radiological Protection, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), International Atomic Energy Agency, and the Committee on Protection Against Ionizing Radiations of the United Kingdom's Medical Research Council. In addition, a review has been made of the practices and procedures in the agricultural and food processing fields that might be useful in reducing potential radionuclide intake.

1.10 Upon invitation from the Federal Radiation Council, the National Academy of Sciences - National Research Council (NAS-NRC) selected a committee of experts to prepare a summary of the biological effects to be expected in man from irradiation by strontium-89, strontium-90, and cesium-137. The committee's findings have been helpful to the Council in developing guidance presented in this report.

1.11 The staff also convened two ad hoc panels of scientists actively engaged in research projects involving strontium and cesium; one panel to provide data on the biological, chemical and physical factors involving radioactive contamination of pasture, milk, and other foods; and the second panel to provide information on the dosimetric relations for these radionuclides. Applicable information provided by these panels has been incorporated into this report.

SECTION II

GENERAL CONSIDERATIONS

Origin and Distribution of Radioactive Materials in the Environment

2.1 The origin and distribution of radioactive materials injected into the atmosphere and their transport mechanisms through the environment to man have been studied intensively both nationally and internationally for the past decade in connection with the atmospheric testing of nuclear weapons. The past and anticipated concentrations of radioactive materials in the environment from weapons testing through 1962 have been studied and evaluated by the Council in its Report Nos. 3, 4, and 6.

2.2 When radioactive materials are released to the atmosphere at ground level, as would generally be the case from an industrial accident, dispersion in the troposphere is limited in extent. In this case, a single incident may cause deposition of high concentrations of radioactive materials within limited areas. Similar localized high-level deposition might also occur with tropospheric fallout deposited under unusual meteorological conditions.

2.3 Material injected into the stratosphere by nuclear weapons tests eventually descends to the troposphere from which it is deposited on the earth's surface. During storage in the stratosphere, short-lived radionuclides decay essentially to zero. Long-lived radionuclides that find their way to the troposphere deposit relatively uniformly on a regional basis, although the quantities vary with latitude and with rainfall. A somewhat similar distribution pattern of short-lived radioactive material such as iodine-131 has been observed in the United States for the tropospheric distribution of debris from tests conducted outside the United States.

2.4 Thus, from past experience one can distinguish two limiting situations of environmental deposition. The first situation (see Section III) can be characterized as a high level of contamination that is limited in time and geographical area. This situation is generally identified with an accidental release of material from an industrial source or as the result of a localized high-level contamination resulting from deposition of tropospheric fallout during unusual meteorological conditions. The second situation (see Section IV) can be characterized as a geographically widespread, low level contamination, resulting from relatively uniform deposition of radioactive materials originally injected into the troposphere or stratosphere. This situation is generally identified with nuclear explosions in the atmosphere. There may be conditions which fall between these two situations. However, for these intermediate cases, it is difficult to predict the relative magnitude of such factors as areas involved, crops affected, and the population at risk.

Radioactive Nuclides of Interest

2.5 Although nuclear fission produces many nuclides, most of which are radioactive, their chemical and physical properties are such that few of them are of biological concern as potential radioactive contaminants of food. Some of these radionuclides have such short radioactive half lives that their radioactive decay to stable nuclides is essentially complete before the food is consumed. Those of principal interest are isotopes of elements readily utilized by vegetation or animals and of sufficiently long radioactive half lives that much of their radioactivity will not have disappeared before the food is consumed.

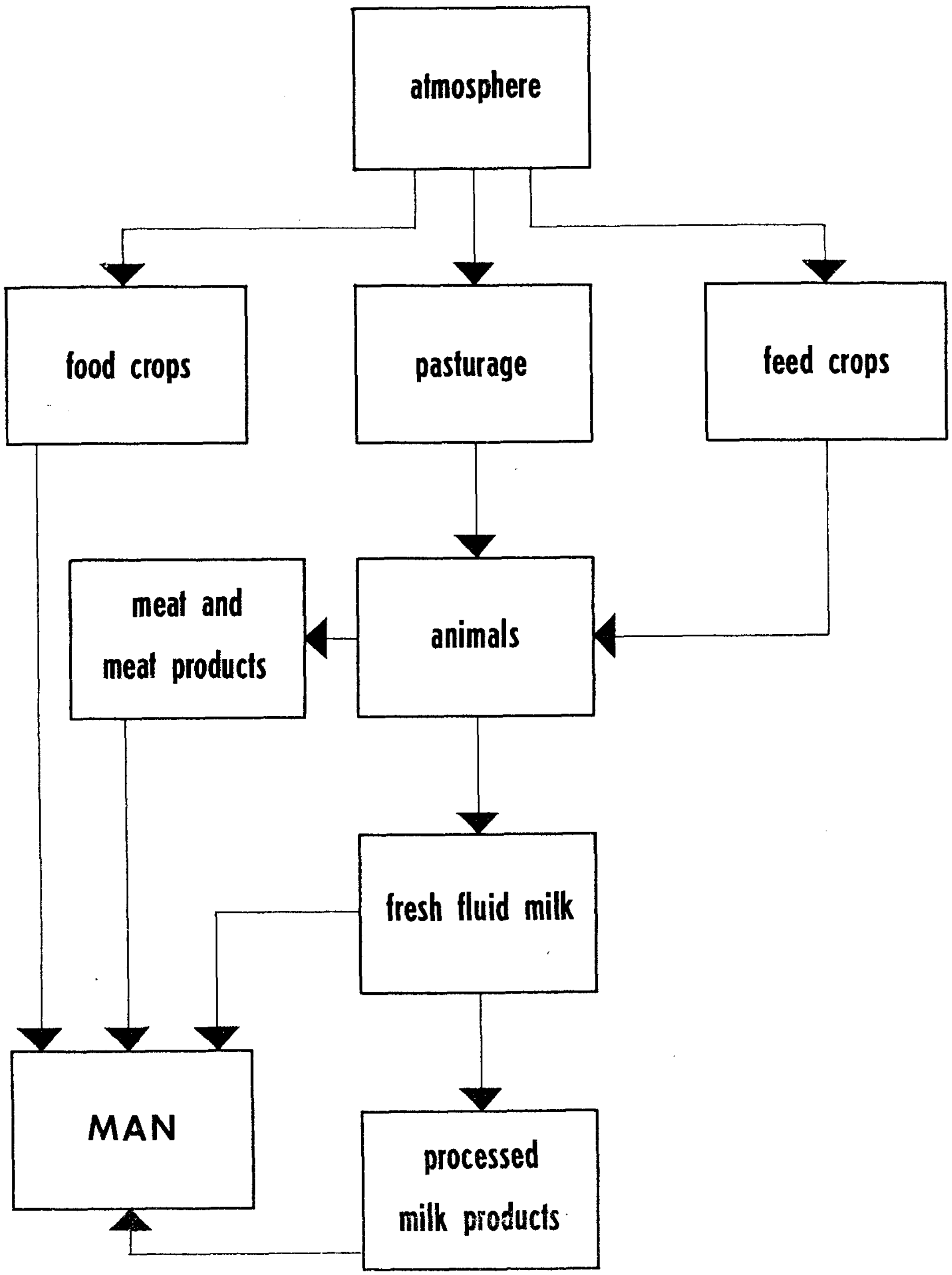
2.6 The relative importance of different radionuclides may depend on additional factors such as: the time that elapses between fission and the release of fission products to the environment; chemical or physical separation or fractionation; conditions of release; and season of the year. For example, in unseparated fission products only a few days of age, the properties of iodine make it the most important radionuclide; in fission products aged a few weeks the longer-lived strontium-89, strontium-90, and cesium-137 are the nuclides of importance. Studies of possible types of release have lead to the conclusion that events requiring protective actions are most likely to involve iodine-131.

The Transmission Pathways

2.7 The transmission pathways of radioactive material from the atmosphere through the food chain to man are shown in Figure 1. The radioactive material is scavenged from the atmosphere by meteorological processes, particularly rain. The most serious contamination problems would arise from direct deposition of the radionuclides on animal feed crops or on food crops directly consumed by man. Following the initial deposition on vegetation the radioactive materials tend to be removed by various processes, such as being washed off by rain or being blown off by the wind. The extent to which such removal occurs depends on a number of

FIGURE I

IMPORTANT STEPS IN THE TRANSMISSION OF RADIOACTIVE MATERIAL THROUGH THE FOOD CHAIN TO MAN



considerations, including particle size and chemical properties of the material deposited and environmental or biological factors.

2.8 The time of deposition relative to the various stages in the plant growth cycle is a major factor affecting the projected intake by man resulting from a given deposition. Much less radioactive material will enter the food chain if the deposition occurs during a period when there is less vegetation or when animals are not on pasture than if the deposition immediately precedes the harvest of a crop. With increasing time between deposition and harvest the transmission of radioactive materials through the food chain would diminish as a result of dilution by new plant growth, removal by weathering and decay, and in some instances by fixation in the soil.

2.9 As seen in Figure 1, man's ingestion of radioactive material may result from contaminated food crops, from contaminated meat or meat products, and from contaminated milk or milk products. The relative importance of the various pathways of intake depends on the radioactive half lives of the radionuclides, the rate and routes by which they pass through the transmission chain, and the dietary habits of the population.

2.10 The immediate and usually the most significant transmission of all these radionuclides will occur through the pasture–cow–milk–man pathway. Because of the various types of plant losses the immediate phase will ordinarily not be of importance after the first 100 days following deposition.

2.11 A later transmission of radionuclides through milk may occur from use of stored feed if this feed was contaminated in the field at the time of the deposition. The relative importance of this pathway may vary greatly due to differences in time between deposition and harvest, the portion of the feed supply contaminated, and the use of the feed supply.

2.12 Foods other than milk may be contaminated to some extent as a result of deposition of radionuclides on food crops or on pasture and feed crops used for meat animals. The variables involved are similar to those of the transmission to milk through stored feed. Cesium-137 would usually be the only significant contaminant present in meat.

2.13 After the first year there may be a residual problem resulting from deposition on soil and subsequent root uptake. This problem would generally concern only strontium-90. Strontium-89 would be essentially removed by radioactive decay and cesium-137 in the soil is generally unavailable to plants.

2.14 Once the radioactive material is ingested by man, the uptake depends upon the chemical properties of the elements and the physiology of the organ involved. Thus, iodine-131 tends to concentrate in the thyroid and strontium-89 and-90 in the bone, while cesium-137 is more-or-less uniformly distributed throughout the body.

<u>Concentrations of Radionuclides in Milk and Projected Intake by Man Following a Contaminating Event</u>

2.15 The ad hoc panel that provided data on the factors involving radioactive contamination of pasture, milk and other foods following a postulated acute deposition, used the following assumptions: (1) physical and chemical properties of the radionuclides were the same as found in worldwide fallout, (2) deposition time was short, (3) deposition was on pasture for dairy cows, and (4) the background and previous cumulative soil contamination levels were negligible. Animal tracer and surveillance network data were used to derive the relationships between concentrations of strontium-89, strontium-90, and cesium-137 in milk and the projected intakes by man.

2.16 Three factors are involved in estimating concentrations of radionuclides in milk after a contaminating event: (1) the secretion rate of the radionuclides into milk following ingestion of a constant daily intake of contaminated vegetation by the cow, (2) reduction of the pasture contamination by weathering and dilution by plant growth, and (3) radioactive decay. When all of these factors are considered, the concentrations of strontium-89, strontium-90, and cesium-137 in milk, as a function of the cow's intake, are described by the equation:

$$A = (ce^{k_1 t}) \quad (1-e^{-k_2 t}) \; (e^{-k_3 t}) \quad (e^{-k_4 t}) \qquad (1)$$

A is the radionuclide concentration in milk; c, k_1, k_2, k_3, and k_4 are constants for a given radionuclide, and t is the time in days after deposition. The first two terms of the equation describe the radionuclide concentration in milk resulting from a constant intake by the cow. The third term describes the rate of loss from vegetation, and the fourth term describes the radioactive decay. This equation is illustrated in Figure 2 as the radionuclide concentration in milk at any time, expressed as a fraction of the maximum concentration (A_m).

2.17 In order to derive the constants (Table 1) for the equation it was necessary to relate the radionuclide concentration in milk to the cow's radionuclide intake during the first day after contamination of the pasture, but knowledge of the cow's intake is not needed to apply the equation. The secretion rate of radionuclides into milk following deposition was estimated from animal experiments in which there was a constant daily intake of the radionuclides by each cow. The rate of loss from vegetation was estimated from surveillance data and from experimental field work. There is a range of measured values for the effective half-time of the radionuclides on grass, most of which are close to 14 days. This value has been selected for use in this report. The effect of radioactive decay in the case of strontium-90 and cesium-137 can be neglected because of the short grazing season compared to the long half lives of these radionuclides.

TABLE 1

Constants for Equation (1)

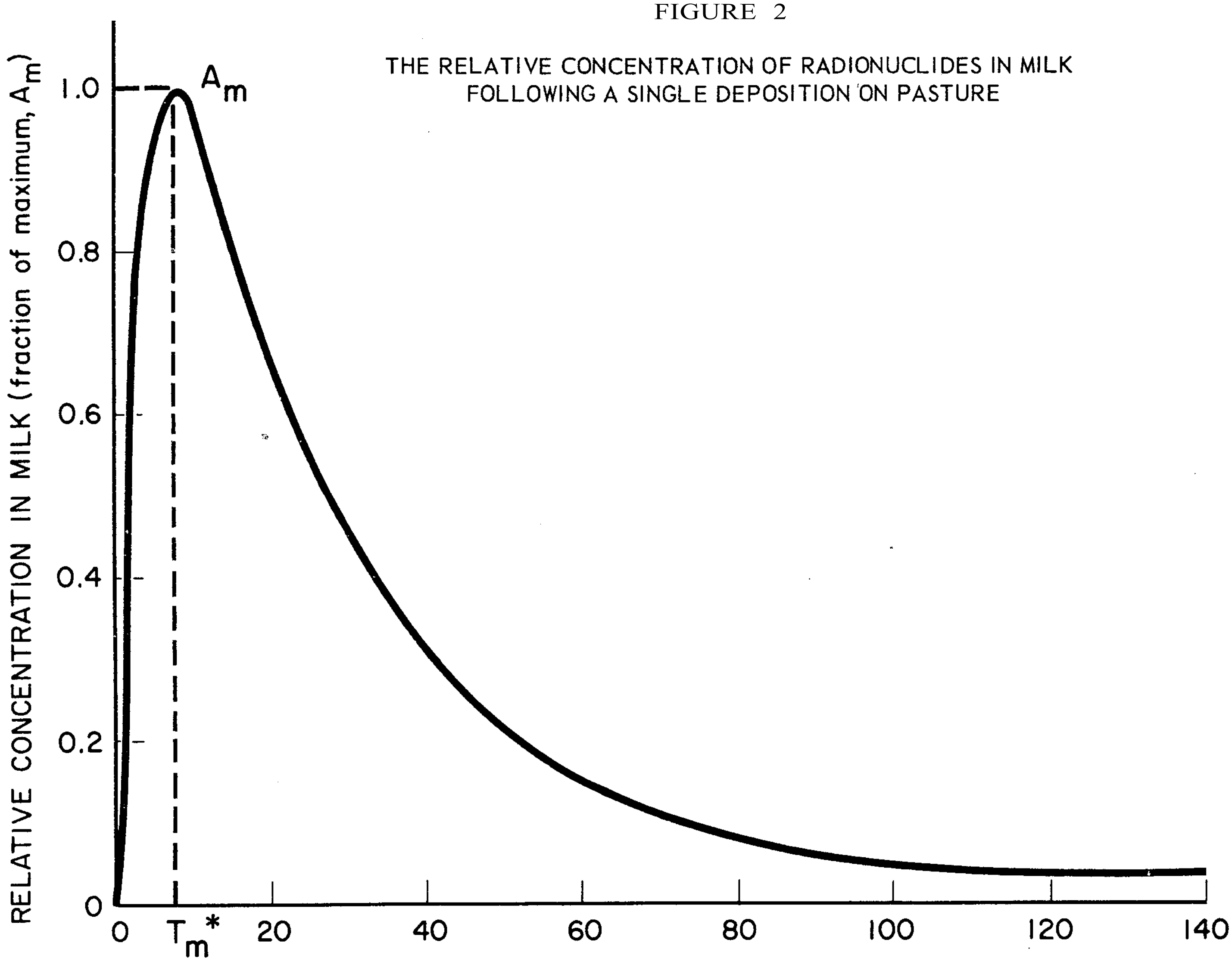
	Strontium-89	Strontium-90	Cesium-137
c $\frac{(nCi/l)}{(nCi/day)}$	0.001	0.001	0.013
k_1 ($days^{-1}$)	0.008	0.008	0.01
k_2 ($days^{-1}$)	0.26	0.26	0.41
k_3 ($days^{-1}$)	0.05	0.05	0.05
k_4 ($days^{-1}$)	0.014	NA	NA

NA = Not applicable
nCi = nanocurie = 1×10^{-9} curie

2.18 The values for T_m, A_m normalized to 1 nanocurie per liter of milk, and the projected intake by man in nanocuries assuming a daily consumption of 1 liter of milk, are listed in Table 2.

FIGURE 2

THE RELATIVE CONCENTRATION OF RADIONUCLIDES IN MILK FOLLOWING A SINGLE DEPOSITION ON PASTURE



* T_m = time maximum concentration occurs.

2.19 The reduction of radionuclide concentration in milk after changing cows from pasture to an uncontaminated feed source has been estimated from the exponential decline of radionuclide concentration in milk following a single intake of a tracer by cows. After the shift to uncontaminated feed, and assuming a constant daily consumption of milk by man, it has been calculated that the remaining intake will equal 2.9, 3.4, and 5.1 times the daily intake of strontium-89, strontium-90, and cesium-137, respectively, at the time of the shift. These relations make it possible to estimate when the shift has to be made in order to avoid various percentages of the total projected intake by man. The results are summarized in Table 3.

TABLE 2

T_m, A_m and Projected Intake by Man after an Acute Contaminating Event Involving Pasture

	Strontium-89	Strontium-90	Cesium-137
T_m (days)	7	7	6
A_m (nCi/liter)	1	1	1
Projected Intake (nCi)	27	33	32

TABLE 3

Intake Avoided Versus Time of Initiating Protective Action

Projected Intake Avoided (%)	Strontium-89 (days)*	Strontium-90 (days)*	Cesium-137 (days)*
50	13	17	14
75	6	7	5
90	2	2	2

*Days after the initial contamination of pasture at which cows would have to be shifted to uncontaminated feed.

Biological Risk Considerations

2.20 The possible biological effects that might follow irradiation of human tissue under differing conditions have been previously reviewed by the FRC in Report Nos. 1 and 2, and more recently by the UNSCEAR (1962 and 1964). In 1964 the Federal Radiation Council asked the National Academy of Sciences - National Research Council to prepare a report on the effects to be expected in man from irradiation by internally deposited strontium-89, strontium-90, and cesium-137 for doses of 25 rads or less from a single contaminating event.

2.21 The Academy in turn established a committee of experts to evaluate the possible effects of these radionuclides in man. The committee considered the particular metabolic properties of these radionuclides, the known effects of irradiation from these and other internally deposited radionuclides, and from external sources. The committee gave particular consideration to the effects that might result from the short-term uptake of any one of these radionuclides by a small fraction of the population.

2.22 The possible risk to segments of a population with a typical distribution of adults, including pregnant women, as well as of children and infants has been examined. The population at risk from local contamination of the environment will be small. In a population with a typical distribution of ages about 50 percent are age 30 or younger, about 10 percent will be of age 4 or younger, and about 2 percent are pregnant women.

2.23 In regard to hereditary effects, it is assumed that any increase in radiation exposure to the genetic cells causes some increase in the mutation rate. The hereditary load induced in a population is proportional to the average dose to the entire population. However, the dose to the individual must also be considered. The NAS-NRC Committee on Genetic Effects of Atomic Radiation expressed the opinion in 1956 that the chance of genetic damage of such a nature as to be expressed in an individual's immediate family would be acceptably small if the dose to the individual was less than 50 rads in 30 years. This opinion was reaffirmed in 1964, and it was concluded that genetic considerations are not limiting under circumstances for which protective action may be needed provided that the exposed population is small and the dose to an individual is small compared to 50 rads (NAS Report to FRC, 1964, par. 4.10).

2.24 Available estimates of the risk of somatic injury following irradiation have beep obtained largely from high dose rates (a few rads or greater per minute), high radiation doses (exceeding 100 rads), or both. These estimates can be considered valid only for the conditions of irradiation for which they were obtained, since there is evidence indicating that the effect of an irradiation depends on both the total dose and the dose rate.

2.25 It has not been established whether internal emitters selectively deposited in bone (bone-seekers) are leukemogenic in man. In addition the specific sites of leukemogenesis, particularly as a function of age, are essentially unknown. However, for the purposes of this report, bone marrow is considered to be the most significant tissue from the standpoint of susceptibility to harmful effects of irradiation.

2.26 Evidence based largely on the survivors of Hiroshima and Nagasaki indicates that, if a population of a million people were to receive a radiation dose of 100 to 500 rads, the average increase in the incidence of leukemia over a period of about 15 years would be from one to two cases per year per rad. (NAS Report to FRC, 1964, par. 5.15; UNSCEAR, 1964, Appendix B, par. 30). An approximately equal number of other neoplasms attributed to the irradiation was found in the same population (UNSCEAR, 1964, Appendix B, par. 179) giving a total increase of 2 to 4 cases per year per million persons per rad averaged over the same number of years.

2.27 An association between antenatal exposure and an increased incidence of cancer in childhood has also been reported. This has been related to single exposures (essentially whole body) to the fetus that may have been as low as 2 to 5 R (NAS Report to FRC, 1964, par. 5.10). The increased incidence of leukemia and total neoplasms calculated on the assumption of linearity was 4 to 10 and 8 to 20 cases per year, respectively, per million fetuses exposed per rad up to the age of 10 years (NAS Report to FRC, 1964, par. 5.11). The risk following antenatal exposure at high dose rate was accordingly estimated to be about 2 to 5 times the risk per rad following postnatal irradiation.

2.28 These estimates of radiation risk cannot be corrected to account for the effects of differences in dose rate and dose distribution. For comparable total doses the dose rate from strontium and cesium under the conditions of present interest is about 10^{-5} to 10^{-6} of the dose rates associated with the estimates of radiation risk in antenatal exposure. Since the strontium nuclides irradiate only that portion of the tissue adjacent to the sites of deposition in the skeleton, the dose distributions are very different from those for which there are risk estimates.

2.29 However, there is evidence from radiobiological experiments indicating that somatic cells, even in the embryo, and genetic cells generally sustain less injury from a given dose if irradiated at low dose rates than if irradiated at high dose rates. For example, genetic studies on mice led to the estimate that when both parents are irradiated at low dose rates, the effectiveness of irradiation in producing mutations may be as little as one-sixth that of the same dose given at high dose rates (FRC Report No. 3, p. 7). Similar observations on the influence of dose rate have been made for radiation-induced leukemogenesis in animals (NAS Report to FRC, 1964, par. 5.17). Hence, the magnitude of the dose rate effect may be considered to be in the same range as the reported difference in radiation sensitivity between antenatal and postnatal populations exposed at high dose rates. From these considerations it is estimated that the upper limit of risk per rad related to antenatal exposure under the conditions of interest (low dose rate) will be no greater than the risk heretofore related to postnatal exposure to the same dose at high dose rates.

Dosimetry Considerations

2.30 The small organ size of infants results in a relatively larger dose per unit intake of radioactive material than for older age groups. Also, from the preceding discussion, the fetus is more susceptible to injury than infants or adults per unit dose. For these reasons special consideration has been given to antenatal and infant exposure.

Strontium

2.31 The metabolism of strontium is linked to the metabolism of calcium in a complex way. The body preferentially absorbs calcium and preferentially excretes strontium. However, strontium and calcium are incorporated into new bone in the same ratio as they exist in blood. It is not known whether the biological risk from radioactive strontium depends upon the dose to bone marrow adjacent to the sites where strontium is incorporated in the skeleton, or upon the mean dose to all the bone marrow in the skeleton. Under the linear hypothesis the mean dose to all bone marrow is the dose of interest for the evaluation of biological risk, and is the one used in this report.

2.32 The radiation dose to mineral bone that would result from the ingestion of radioactive strontium from the diet depends on the fraction of ingested strontium reaching bone and the length of time it remains there. Inadequate knowledge of the way strontium may be initially distributed in the skeleton makes a calculation of radiation dose, particularly to bone marrow, very difficult. If uniformly distributed throughout the mineral bone of the adult, 1 nanocurie of strontium-89 per gram of calcium would result in a dose of 0.3 rad to mineral bone (derived from UNSCEAR, 1962, Annex F, par. 52, p. 356). One nanocurie of strontium-90 per gram calcium uniformly distributed in adult bone would result in a dose of 2.7 rads in a year (UNSCEAR, 1962, Annex F, par. 29, p. 353). The dose to mineral bone of the fetus and infant may be about one-half the adult values because the young skeleton has less mineral per gram of bone, and because the young skeleton absorbs less of the available beta energy (Some Aspects of Internal Irradiation, Pergamon Press, Oxford 1962, p. 447).

2.33 The estimation of the dose to bone marrow resulting from the incorporation of radioactive strontium in the surrounding mineral bone is a complex problem. The energies of the beta particles from the radioactive decay of strontium are distributed over a broad spectrum, and for each energy a specific range of the particle in bone, soft tissue, or in a combination of the two must be considered. The dose to bone marrow from strontium-89 and strontium-90 uniformly distributed in the adult skeleton has been estimated to be about one-fifth the calculated dose to mineral bone for strontium-89 and about one-fourth the dose to mineral bone from strontium-90 (UNSCEAR, 1962). The Federal Radiation Council used a value of one-third for both nuclides in FRC Report No. 2.

2.34 Although the lower density of mineralization in the infant and fetal skeleton results in a lower dose to mineral bone than the dose from the same concentration of strontium in the adult skeleton, the resulting dose to bone marrow of the infant or fetus will be relatively higher for the same reason. Therefore, one-third of the dose that would be calculated for mineral bone per unit of strontium in the adult skeleton is also a reasonable estimate of the dose from the same concentration to bone marrow of the fetus and infant. The calculations in this report accordingly assume that for estimating radiation dose to the bone marrow of a fetus or infant from radioactive strontium in the skeleton (1) the radioactive strontium is uniformly distributed in the mineral bone, (2) a concentration of 1 nanocurie strontium-89 per gram calcium in the skeleton will give a total dose of 0.1 rad to bone marrow, and (3) a concentration of 1 nanocurie strontium-90 per gram calcium in the skeleton will give a dose of 0.9 rad in one year to bone marrow. With present information, these dose conversion factors give the best available estimates of the biologically important dose, i.e., the average dose to bone marrow following short-term intake of radioactive strontium.

2.35 The relationship of strontium and calcium in children's bones compared to the strontium to calcium ratio in the diet is based on results obtained from measurements made on strontium-90 from fallout. The proportion of radioactive strontium incorporated into the skeleton from the diet mainly involves two factors: first, discrimination by the body against strontium in favor of calcium; and second, the amount of calcium with its associated strontium which is incorporated into the skeleton each day by the formation of new bone.

2.36 The first factor, discrimination between strontium and calcium in the passage of these elements from the diet to a given tissue in the body, is usually expressed as the Observed Ratio (OR). The OR relates the ratio of strontium to calcium that exists at equilibrium in a given component of the body to the ratio of strontium to calcium in the diet. If the body component is the bone, then:

$$OR_{bone/diet} = \frac{Sr/Ca \text{ in bone}}{Sr/Ca \text{ in diet}} \qquad (2)$$

The OR, fetal bone to mother's diet is estimated to be about 0.1. The OR, bone to diet changes from about 1 at birth, to about 0.5 at 6 months to 1 year, and to about 0.25 shortly thereafter (NAS Report to FRC, 1964, par. 3.14). An OR of 0.35 has been selected as the most representative value for the age group of interest (i.e., 6 months to 2 years).

2.37 The second factor is related to the sum of the calcium involved in skeletal growth (net accretion) plus the quantity of calcium in the existing skeleton that is replaced (turnover). Mitchell, et al. (J. Biol. Chem. 158, 625, 1945) have estimated the net annual calcium accretion from birth to 20 years, after which skeletal growth ceases. The quantity of calcium in the skeleton at birth and at ages 1 and 2 has been estimated to be 28, 100, and 150 grams, respectively. The estimated net accretion of calcium is 28 grams in the fetal period, 72 grams during the first year of life, and 50 grams in the second year of life. The bone mineral turnover rate during the first two years of life is estimated to be about 50 percent per year (NAS Report to FRC, 1964, par. 3.12). The turnover rate decreases to an adult value of about 1 percent per year in the shafts of long bones and 10 percent in cancellous bone.

2.38 The radiation dose delivered to the skeleton during the first year following a contaminating event varies with the length of time the diet is contaminated. Estimates have been made for a contaminating event that would result in a total intake of one microcurie of strontium-89 or strontium-90 in 100 days, the period of interest for the transmission of these radionuclides through the pasture-cow-milk-man pathway. Assuming that the typical calcium intake is about 1 gram per day, the radioactive strontium intake would then be associated with 100 grams of calcium. Thus, an intake of one microcurie of radioactive strontium in 100 days would result in an average dietary level of 10 nanocuries of radioactive strontium per gram of calcium.

2.39 For estimating dose following the ingestion of radioactive strontium, the ad hoc dosimetry group recommended a model embodying: formation of a specified amount of new bone per day; further resorption and remodeling of a specified amount of existing bone per day; and use of the OR to relate the strontium to calcium ratio in the diet to that in bone. A dynamic model which simulates incremental changes in skeletal strontium on a day to day basis was developed utilizing computer techniques. Evaluation of the results from the computer model indicated that a less refined approach using strontium diet levels averaged for the period of intake and other simplifying assumptions regarding net calcium accretion and bone turnover would provide comparable estimates of dose.

2.40 An estimate of the dose to bone marrow from radioactive strontium in the diet can be reduced to two considerations:

1. An estimate of the average strontium to calcium ratio in the skeleton from average dietary levels for a short-term intake.

2. The use of a dose conversion factor to convert the skeletal concentrations of strontium into dose to the bone marrow.

The average strontium to calcium ratio (R_a) in the skeleton may be estimated from:

$$R_a = R_d \times OR \times F \qquad (3)$$

where:

R_d = strontium to calcium ratio in the diet averaged over the period of intake.

OR = Observed Ratio.

F = Fraction of skeletal calcium incorporated by accretion and turnover during the period of intake.

An estimate of dose (D) can be calculated by:

$$D = R_a \times \text{Dose Conversion Factor} \qquad (4)$$

Application of the appropriate dose conversion factors from par. 2.34 will give the total dose from strontium-89 or the dose in one year from strontium-90, which would result from the calculated average skeletal strontium to calcium ratios.

2.41 For the antenatal period the maximum strontium burden of the developing skeleton would result when the 100 day intake coincides with the third trimester, i.e., when essentially all of the mineralization of the fetal skeleton occurs. Thus F would be 1.0. Using an R_d of 10 nanocuries of radioactive strontium (denoted as Sr* in the equations) per gram of calcium in the mother's diet and an OR of 0.1 for mother's diet to fetal bone, the average strontium to calcium ratio in the fetal skeleton would be:

$$R_a = 10 \times 0.1 \times 1.0 = 1.0 \ \frac{\text{nCi Sr*}}{\text{g Ca}}$$

2.42 For the infant one to two years old, the fraction F must be estimated from the annual net accretion and turnover. The net accretion during the second year of life is estimated to be about 50 grams of calcium. The turnover is estimated to be an additional 50 grams of calcium during this year. The fraction of calcium in the skeleton that is incorporated during the 100 day intake is:

$$F = \frac{50 + 50}{150} \times \frac{100}{365} = 0.18$$

Using an R_d of 10 nanocuries of strontium per gram of calcium in the diet and an OR of 0.35, the average strontium to calcium ratio in the infant skeleton would be:

$$R_a = 10 \times 0.35 \times 0.18 = \frac{0.65 \text{ nCi Sr*}}{\text{g Ca}}$$

Strontium-89

2.43 The total dose resulting from the 100 day intake of strontium-89 can be calculated using the dose conversion factor previously given. A concentration of 1 nanocurie strontium-89 per gram of calcium in the skeleton would give a total dose of 0.1 rad to bone marrow. For the two cases presented the doses would be:

Fetus: $D = 1.0 \times 0.1 = 0.1$ rad

Infant: $D = 0.65 \times 0.1 = 0.065$ rad

Thus the resulting total dose to the bone marrow of the infant is estimated to be about two-thirds of the total dose to the bone marrow of the fetus for the same intake by the infant and the pregnant mother. This difference is less than the uncertainties inherent in the estimate, and is not considered significant.

Strontium-90

2.44 Using the relationship that one nanocurie of strontium-90 per gram of calcium in the skeleton will give dose of 0.9 rad in one year to the bone marrow, the doses from strontium-90 for the two cases presented would be:

Fetus: $D = 1.0 \times 0.9 = 0.9$ rad in one year

Infant: $D = 0.65 \times 0.9 = 0.6$ rad in one year

2.45 Since one trimester is about one-fourth of a year, the dose to the fetus before birth would be about one-fourth the dose in one year estimated from the strontium-90 to calcium ratio in the fetal skeleton, or approximately 0.2 rad. The strontium-90 burden at birth would be one nanocurie of strontium-90 per gram of calcium times 28 grams of calcium or 28 nanocuries. With a bone turnover rate of 50 percent per year there would be 28 x 0.5 = 14 nanocuries strontium-90 per 100 grams calcium in the skeleton at age 1, and 7 nanocuries strontium-90 per 150 grams of calcium at age 2. These concentrations of strontium-90 give dose rates of 0.1 and 0.04 rad per year, respectively. Computer analysis led to the estimate that the total (70 year) dose from a short-term intake of strontium-90 would be about 5 times the dose in the year when the infant is age 1. Assuming that the dose in a year can be reasonably approximated by the average of the dose rates at the beginning and end of the year, the projected total dose to bone marrow of an individual whose mother had an intake of 1 microcurie of strontium-90 during the last 3 months of pregnancy would be:

$$D = 0.2 + \left[\frac{0.9 + 0.1}{2}\right] + 5\left[\frac{0.1 + 0.04}{2}\right] = 1.1 \text{ rads, total dose}$$

The total bone marrow dose for the infant would be:

$$D = 0.6 \times 5 = 3 \text{ rads, total dose}$$

It is concluded that for an identical intake over 100 days by the infant and by the pregnant woman the total dose to the infant would be approximately three times the total dose to the individual exposed as a fetus.

2.46 In view of the considerations discussed in the previous paragraphs, the estimates of projected doses to individuals in the general population are based on a dose of 0.1 rad to bone marrow following the ingestion of 1 microcurie of strontium-89 associated with 100 grams of calcium, and a dose of 0.6 rad in the first year with a total dose of 3 rads to bone marrow following the ingestion of 1 microcurie of strontium-90 associated with 100 grams of calcium.

Cesium-137

2.47 Cesium-137 is an alkali metal which is chemically and metabolically similar to potassium. Its distribution after ingestion is relatively uniform throughout the body resulting in irradiation of the whole body, including bone marrow. It is eliminated from the body at a rate which may be expressed in terms of the biological half life. This is the time required for the body to eliminate one-half of an initial body burden of cesium.

2.48 The dose resulting from a given intake of cesium-137 is directly proportional to the biological half life and inversely proportional to the lean body mass. A review of the literature indicates that the biological half life ranges from about 60 to 180 days in adults. The value for normal adults in the general population is estimated to be about 100 days (NAS Report to FRC, 1964, par. 2.12). The data for persons younger than 25 years suggest that the biological half life before maturity may be a function of age.

Biological half lives of about 20 days or less have been reported for infants. For this report a value of 30 days is used as the biological half life of cesium-137 in infants.

2.49 The radiation dose per microcurie of cesium-137 ingested may be approximately related to the body size and the biological half life by the formula:

$$D = \frac{I}{W} \times 0.03 \times 1.44\ T_B \qquad (5)$$

where:

D = the total dose in rads

I = the total intake in microcuries of cesium-137

W = the body weight in kilograms

0.03 = kilogram rads per microcurie day (based on the absorption of 0.59 MeV per disintegration).

T_B = the biological half life in days

2.50 An infant weighing 10 kg (about 22 pounds) and ingesting 1 microcurie of cesium-137 would receive a dose of 0.13 rad. An adult weighing 70 kg and ingesting 1 microcurie of cesium-137 would receive a dose of 0.06 rad. The dose rate to the fetus is considered to be the same as the dose rate to the mother. Therefore, for equal intakes of cesium-137 the dose to the infant would be about twice the maximum dose to the fetus. Most of the dose from a short-term intake of cesium-137 would be received in one year. A value of 0.13 rad following the ingestion of 1 microcurie of cesium-137 is used to estimate projected doses to the general population.

Protective Actions and Guides

2.51 As stated in FRC Report No. 5, a protective action is an action or measure taken to avoid most of the exposure to radiation that would occur from future ingestion of foods contaminated with radioactive materials. In the present report the concept of protective action must be extended in its application because the longer half lives of strontium-90 and cesium-137 may lead to a more persistent contamination of a number of food and animal feed crops. Therefore, in order to achieve a substantial reduction in the total dose, it is necessary to consider protective actions against those animal feed crops or food crops that would make major contributions to that dose.

2.52 Some basic considerations in the development of protective actions and guides are:

1. The occurrence of an acute contaminating event which will require protective action is considered to be so infrequent that it is unlikely that the same individual will be exposed to more than one event.

2. Exposure to the public from radionuclides in the environment is directly related to the concentration of the radionuclides in food supplies and the length of time (weeks, months, or years) over which unusual exposures would be expected to occur. The need for protective actions is generally independent of the source of contamination.

3. The substitution of food or feeds of lower radionuclide content for contaminated products is both effective and practicable.

4. The potential intake of radionuclides by individuals in the general public from radionuclides in the environment can be reduced whenever modifications in the normal production, processing, distribution, or dietary practices are considered to be less objectionable than the radiation risk that would otherwise have to be accepted.

5. Protective actions, by their very nature, are short-term modifications in such practices.

6. If the contamination of a particular crop or dietary component is so high that it would not be acceptable for local use, the crop or dietary component is not considered acceptable for use in other areas to which it may be transported.

2.53 Also, in the development of guidance for taking protective action it is necessary to consider:

1. The possible risk to health associated with the projected dose to the population from radioactive materials.

2. The amount by which the projected dose can be reduced by taking certain actions.

3. The total impact, including risks to health, associated with these actions.

4. The feasibility of taking the actions.

2.54 Decisions to implement protective actions involve a comparison of the risk due to radiation exposure with the undesirable features of the contemplated actions. The critical decisions to be made are whether to permit unrestricted use of feed crops or food products, to place restrictions on the normal use of feed crops or food products, or to destroy feed crops or food products. The value of a protective action depends on how much the projected dose per individual can be reduced by the action and the number of people affected. Protective actions affecting a particular population group will yield a greater return in relation to their disadvantages if projected doses are high rather than low. Since high levels of contamination probably will be limited to small areas, protective actions are more likely to be required in such areas rather than over large regions.

2.55 The Council has adopted the term "Protective Action Guide" (PAG), defined as the projected absorbed dose to individuals in the general population that warrants protective action following a contaminating event. The projected dose is the dose that would be received by individuals in the population group from the contaminating event if no protective action were taken. If the projected dose exceeds the PAG, protective action is indicated.

2.56 Protective actions are appropriate when the health benefits associated with the reduction in exposure to be achieved are sufficient to offset the undesirable features of the protective actions. The PAG's represent the judgment as to where this balance should be for the conditions considered most likely to occur. If, in a particular situation, there is available an effective action with low total impact, initiation of such action at a projected dose lower than the PAG may be justifiable. If only high impact action would be effective, initiation of such action may be justifiable only at a projected dose higher than the PAG. The types of actions considered in the development of guidance in this report include:

1. Altering production, processing, or distribution practices affecting the movement of radioactive contamination through the food chain and into the human body. This action may include storage of food supplies and animal feeds to allow for radioactive decay.

2. Diverting affected products to uses other than human consumption.

3. Condemning affected products.

2.57 An alteration of the normal diet of an individual is generally less desirable than the measures listed and should not be undertaken except on the personal advice of a physician.

2.58 In the situations where there are slowly increasing levels of widespread contamination over a period of months or years throughout the nation's food producing areas, protective actions presently contemplated for acute, local contamination situations would not be effective. The consideration of long duration protective actions to reduce the average intake of radioactive materials for large populations involves many complex interacting factors of available, or potentially available, resources. In addition, a decision to require changes in agricultural and food processing practices or dietary habits could be implemented only through policy decisions involving land utilization, work force distribution, and the allocation of technical talent to the long-term control effort.

SECTION III

THE ACUTE LOCALIZED CONTAMINATING EVENT

3.1 Situations justifying protective actions could occur from such events as an industrial accident, possibly involving a nuclear reactor or a nuclear fuel processing plant, and release of radioactive materials from nuclear explosions. The considerations involved in determining appropriate criteria for protective action following an acute contaminating event have led to the development of three categories of dietary pathways. Categories I and II relate to intake in the first year following acute deposition, while Category III considers intake after the first year.

3.2 Category I is concerned with the immediate transmission of the radionuclides through the pasture-cow-milk-man pathway. The three nuclides of interest may be transmitted through this pathway simultaneously when they are deposited simultaneously on pasture. Experimental data indicate that nearly all the radioactive materials appearing in milk through this pathway will have occured within 100 days, and protective actions may have to be applied for this length of time. Protective action must be initiated within about a week to be effective in averting most of the potential exposure. This category of transmission may be the only one of importance for strontium-89 because of its relatively short radioactive half life (50.5 days).

3.3 Category II is concerned with the transmission of radionuclides to man through dietary pathways other than that specified as Category I during the first year following an acute contaminating event. This involves the use of feed crops for animals, including dairy cattle, and plant products used directly for human consumption. The radioactive materials initially deposited on such crops in the field do not gain access to the human food chain until after the crops are harvested. Immediate action to reduce the potential intake will not usually be required because of the normal delay in the use of such crops. However, an early decision will be required as to the need for examination of the radionuclide content of harvested crops before they enter normal marketing channels. Strontium-90 and cesium-137 may be transmitted through the cow's feed to milk; cesium-137, in particular, may be transmitted through feed to meat; both may be transmitted to man through the direct consumption of plant products.

3.4 Category III is primarily concerned with the long-term transmission of strontium-90 through soil into plants in the years following a contaminating event. Residual contamination of cesium-137 on pasture when there is a heavy root mat may be a consideration for one to two years following a sufficiently severe contaminating event. Because of the long lead time available to assess the possible radionuclide intakes, immediate action is not necessary. Any action that may be taken must be based on the long-term reduction of the radionuclide concentrations in products grown in the area.

3.5 In considering the desirability of initiating protective actions following a contaminating event, it is necessary to consider the three categories separately. The benefits of a protective action taken in one category are largely independent of whether action is taken in another. Individuals may be exposed to radioactivity from all three categories; however, the guides for individual categories recommended in this report are sufficiently conservative (i.e., low) that it is unnecessary to provide an additional limitation on combined doses. Actions that are likely to be taken in Categories I and II would be effective against any of the three nuclides. Since all nuclides contribute to bone marrow dose, the sum of the projected doses to the bone marrow should be compared to the numerical value of the respective guide in the appropriate category when the need for protective action is considered.

<u>Guidance Applicable to Category I</u>

3.6 Conditions in Category I develop rapidly from the onset of radionuclide deposition, and protective actions must be initiated within about a week to avert most of the intake. The protective actions considered effective are:

1. The change of cattle from pasture to stored feed.

2. The substitution of unaffected fresh milk for affected fresh milk by alteration of processing or distributing practices, with subsequent diversion (depending on the radionuclides) or disposal of contaminated milk.

Since these actions are effective for all radionuclides of concern, actions taken for one contaminant will simultaneously reduce the intake of others. Protective actions to avert exposure may be appropriate for a shorter or longer time than

100 days, depending on the circumstances.

3.7 The concept of the Protective Action Guide, as presented in Report No. 5, was developed for use as guidance in situations involving the rapid transmission of radionuclides from pasture to milk to man with the inherent limitations on the types of effective actions for which the necessary resources would be generally available. Such a situation has many of the characteristics of an emergency requiring an immediate decision as to the need for protective actions. The possible need for early actions to avoid most of the projected intake that may result from an acute localized contaminating event involving strontium-89, strontium-90, and cesium-137 is also present in Category I.

3.8 In the application of the PAG's the following guidance is provided:

1. If the projected dose exceeds the PAG, protective action is indicated.

2. The amount of effort that properly may be given to protective action will increase as the projected dose increases.

3. The objective of any action is to achieve a substantial reduction of the dose that would otherwise occur--not to limit it to some prespecified value.

4. The value of the proposed protective actions must be weighed against their total impact. Each situation should be evaluated individually. As the projected doses become less the value of protective actions becomes correspondingly less.

3.9 The guidance applicable to strontium-89, strontium-90, and cesium-137 is given in terms of the projected dose to the whole body or bone marrow. Because of the risk associated with irradiation of bone marrow or the whole body as compared to irradiation of the thyroid, and the comparability of the protective actions available to avert the exposure, it is considered appropriate that the PAG's applicable to these radionuclides be lower than the PAG recommended for iodine-131. In view of these considerations it is recommended that:

1. The PAG for the transmission of strontium-89, strontium-90, and cesium-137 through milk under the

conditions of Category I be a mean dose of 10 rads in the first year the bone marrow or whole bodyof individuals in the general population; and provided further, that the total dose resulting from Category I not exceed 15 rads. For purposes of applying this guide the total dose from strontium-89 and cesium-137 is assumed to be the same as the dose in the first year, whereas the total dose from strontium-90 is assumed to be five times the dose from strontium-90 in the first year. As an operational technique it is assumed that the guide will be met effectively if the average projected dose to a suitable sample of the population (children approximately 1 year of age) does not exceed one-third of the numerical value prescribed for the individual.

3.10 For the radionuclides of interest, the total intake by man in Category I following a contaminating event is estimated from the assumptions that: (1) Equation (1) describes the radionuclide concentrations in milk as a function of time; (2) the average calcium content of milk is 1 gram per liter; (3) the daily intake of milk is 1 liter; and (4) the total intake will occur within 100 days. Tables 4, 5 and 6 are based on these assumptions and the relationships between total intake and projected dose, given in paragraphs 2.46 and 2.50.

TABLE 4

Relation Between Strontium-89 Intake Through Milk and the Average Dose to Bone Marrow*

Maximum Concentration in Milk (nCi ^{89}Sr/1)	Total Intake (μCi ^{89}Sr)	Average Dose to Bone Marrow (rads)
63	1.7	0.17
370	10	1.0
740	20	2.0
1110	30	3.0
1870	50	5.0
3700	100	10
18700	500	50

*Based on a dose of 0.1 rad to bone marrow following an intake of 1 microcurie associated with 100 grams of calcium

μCi = microcurie = 1×10^{-6} curie

TABLE 5

Relation Between Strontium-90 Intake Through Milk and the Average Dose to Bone Marrow*

Maximum Concentration in Milk** (nCi ^{90}Sr/l)	Total Intake (μCi ^{90}Sr)	Average Dose to Bone Marrow in First Year (rads)	Total Dose to Bone Marrow (rads)
8	0.28	0.17	0.85
51	1.67	1.0	5.0
100	3.34	2.0	10.0
155	5.0	3.0	15.0
250	8.3	5.0	25.0
510	16.7	10	50

*Based on a dose of 0.6 rad in the first year and a total (70-year) dose of 3 rads to bone marrow following an intake of one microcurie associated with 100 grams of calcium.

**Numbers below 100 have been rounded to the nearest unit; numbers above 100 to the nearest 5 units.

μCi = microcurie = 1×10^{-6} curie

TABLE 6

Relation Between Cesium-137 Intake Through Milk and the Dose to Whole Body*

Maximum Concentration in Milk (nCi ^{137}Cs/l)	Total Intake (μCi ^{137}Cs)	Dose to Whole Body (rads)
41	1.3	0.17
240	7.7	1.0
480	15.4	2.0
720	23	3.0
1190	38	5.0
2400	77	10

*Based on a dose of 0.13 rad following an intake of one microcurie

μCi = microcurie = 1×10^{-6} curie

Guidance Applicable to Category II

3.11 Conditions in Category II that may warrant action develop more slowly, in comparison to those of Category I, and generally permit more time for application of protective actions after the deposition of radioactive material has occured. The time of deposition of radioactivity relative to the various stages in the plant growth cycle will be a major factor affecting the concentration of radionuclides in food and feed. Although the variations can be large, depending on the time of year and the particular produce grown in the contaminated area, the concentrations of radionuclides reaching man through Category II pathways will be less, in most cases, than those in Category I. The need for initiating a program to assess the degree of contamination and the use of crops in Category II can generally be deduced from the situation found in Category I. Protective actions usually will not be required in Category II if they were not required in Category I.

3.12 The significance of radioactive contamination should be evaluated in terms of potential daily and total intakes by persons who are assumed to derive major portions of their diets from the use of locally grown crops. A wide range of situations may exist within Category II. It is generally impossible to predict total radiation doses solely from the degree of contamination of a particular crop. The complexity of such situations and the fact that for most crops immediate action, beyond assuring that the questionable crops are not marketed before appropriate assessment can be made, make it impractical to provide numerical guides applicable to individual products. However, if it appears that the total projected dose to a suitable sample of a population group from the use of all crops in Category II is larger than the PAG recommended for this category, protective actions should be initiated against those crops that would make major contributions to that dose. In order to meet the objective of Item 6, paragraph 2.52, this suitable sample would be from a group considered to live in a contaminated area and also be considered to make maximum utilization of locally produced food products.

3.13 Depending on the circumstances, the protective actions considered appropriate for Category II are:

1. Modification of animal feed utilization practices or of food processing and marketing practices.

2. Diversion of one or more crops so that the

radionuclides of interest are removed from access to the human food chain.

3. Destruction of one or more food crops or animal feed crops.

The effectiveness of the actions in eliminating potential intake from the use of the crops increases in the order listed. The kinds of protective action applicable to the use of animal feed crops and food crops directly contaminated by deposition and their relative feasibility can be expected to vary quite widely from one situation to another. Destruction of food crops should seldom be required. The selection of individual foodstuffs for disposal or for diversion to non-human use will depend on many factors, including: (1) the fractional contribution of radioactive material that each dietary item makes to the total diet, assuming a normal diet; (2) the reduction in projected dose that could result from the elimination of each dietary item; and (3) the possible access to the food chain through diversion to alternate non-human uses.

3.14 In view of these considerations it is recommended that:

2. The Protective Action Guide for the transmission of strontium-89, strontium-90, and cesium-137 through food crops or animal feed crops under the conditions in Category II be a dose of 5 rads in the first year to the bone marrow or whole body of individuals in the general population. As an operational technique it is assumed that the guide will be met effectively if the average projected dose to a suitable sample of the local population is no larger than 2 rads in the first year to the whole body or bone marrow.

3.15 The intent of the recommendation is to discourage deliberate introduction of contaminated foods into supplies of uncontaminated foods as an acceptable means of solving a problem involving radioactive contamination of the environment. It is recognized that all crops that might be affected by a contaminating event will not be harvested at the same time, In addition, some crops might not normally be used until more than a year after the event. The PAG for this category is intended to apply to the evaluation of the projected dose from the use of crops that were contaminated at the time of the event and are harvested within a year.

3.16 The transmission of strontium-89, particularly to children approximately 1 year of age, through dietary products other than milk should generally be insignificant in comparision to its transmission through milk. Under certain conditions it is conceivable that significant quantities of strontium-89 could be transmitted to milk if contaminated crops are used to feed dairy cattle before the strontium-89 has been lost by radioactive decay. Once the crop has been harvested, strontium-89 is lost only by the process of radioactive decay during storage, and the relationship between the concentration of strontium-89 in milk and the total intake differs from that in Category I. The maximum projected intake in this case is 74 (1.44 x radioactive half life) times the measured concentration per liter of milk assuming a consumption of 1 liter of milk per day.

3.17 The strontium-90 and cesium-137 content of animal feed depends on the concentration at the time the crop is harvested. There is no significant loss of these radionuclides by radioactive decay in time periods of 1 to 2 years. If the feed is used for dairy cows the strontium-90 and cesium-137 concentration in milk would reach a steady state value related to the cow's daily intake. The concentration in milk would remain at that value as long as the feed is used. Therefore, the relation between the concentration of strontium-90 and cesium-137 in milk and the total quantity secreted into the milk would vary, depending on how long the particular feed crop is used. However, this quantity can be estimated in advance if the concentrations in the feed are known and the use of the feed has been determined.

3.18 In addition to the transmission of strontium-90 and cesium-137 to milk through the use of contaminated crops for feeding dairy cattle, the possible contribution resulting from the use of other crops such as fruits, vegetables, or cereal grains growing in the same area must also be considered. In these cases, it is expected that the largest part of the contamination will be associated with one or two particular crops and the action should be directed at eliminating this part of the potential exposure.

3.19 The relationship between the total intake of strontium-89 and strontium-90 and the projected doses as shown in columns 2 and 3 of Tables 4 and 5 is valid if the particular intake is to be evaluated over a period of 1 to 3 months. The relationship between the total intake of cesium-137 and dose shown in columns 2 and 3 of Table 6 may be used in estimating the projected dose from cesium-137.

Guidance Applicable to Category III

3.20 In this category there can be extremely wide variations in the situations that might exist in relation to (1) areas involved, (2) crops affected, (3) possible rate of the decrease in strontium-90 gaining access to plants, and (4) possible actions. In addition, one is now concerned with problems of long-term chronic exposure. Actions that may be effective in Category III involve major long-term changes in farming practices such as selection of crops, chemical or mechanical treatment of soil, land utilization, or all three of these. Following a sufficiently severe event, long-term restrictions may be placed on the use of farmland for food or feed production. The range of considerations that may enter into a decision to take action in this category together with the length of time available for detailed evaluations make it less meaningful to provide a numerical PAG than to provide guidance for evaluation of long-term situations. The nature of the situation is such that detailed evaluation would not be required except in situations in which levels of environmental contamination are greater than those that might occur under guidance provided for normal peacetime operations.

3.21 In view of these considerations it is recommended that:

> 3. The desirability of protective action against exposure to environmental radioactivity from situations in Category III be determined on a case-by-case basis. If it appears that annual doses to the bone marrow after the first year may exceed 0.5 rad to individuals or 0.2 rad to a suitable sample of the population, such situations shall be appropriately evaluated.

3.22 Strontium-89 will have essentially disappeared through radioactive decay within 12 to 18 months after the initial deposition. This radionuclide, therefore, is not a consideration in the utilization of land in the years following a high deposition.

3.23 Long-term exposure from strontium-90 entering the food chain through root mats on pastures or through the soil into plants may be an important factor in land utilization for several years following a sufficiently high deposition of strontium-90 in the environment. Land used for pastures, animal feed crops, or other crops such as fruits and vegetables may be affected in varying degrees.

3.24 Cesium-137, particularly on pastures with a heavy root mat, may be an important factor in land utilization for 1 to 2 years after an acute contaminating event. Direct transmission to plants from cesium-137 in the soil is generally not expected to be limiting since cesium-137 is tenaciously bound by soil particles.

SECTION IV

WORLDWIDE CONTAMINATION FROM STRATOSPHERIC FALLOUT

4.1 Stratospheric fallout from past atmospheric testing of nuclear weapons has led to a worldwide deposition of fission products in the environment. It has led to a generally fluctuating but gradually increasing level of long lived radionuclides in food products. These levels reached their peak in 1964. All food supplies may be affected simultaneously to a greater or lesser degree but the average radionuclide levels in the food produced in a large area, such as a state, are more significant than local fluctuations within the area. The general situation has been studied by the FRC from the standpoint of worldwide fallout from past atmospheric testing (FRC Report Nos. 3, 4, and 6).

4.2 It appears that the intra-regional variations of food contamination are relatively small. In 1963 the highest annual average strontium-90 content of milk from stations among "wet" areas was less than three times the annual average of all stations in these areas. The highest monthly average for this station was about twice its annual average and its highest weekly sample was about three times its annual average. In the United States the annual average of the station with the highest average was about 20 times that of the station with the lowest average. Regional variations in cesium-137 and strontium-89 concentrations were comparable. (FRC Report No. 6)

4.3 The relationship between the amount of fallout deposited per unit area and the resultant dietary intake by man is not constant, but is influenced by a variety of factors. These include those factors influencing the subsequent movement of radionuclides through the environment to the diet and the dietary habits of specific population groups or individuals.

4.4 The studies of fallout in the United States from past testing (FRC Report Nos. 4 and 6) have indicated that:

1. From tests conducted in 1962, strontium-89 gave an estimated average dose of 0.04 rad to bone and 0.01 rad to bone marrow. These doses were divided about equally between 1962 and 1963, giving an annual dose in each year equal to about 3 to 4 percent of the numerical values of the RPG's for bone and bone marrow. In 1964 the estimated dose from strontium-89 was negligible.

2. The average annual strontium-90 content of the total diet in the "wet" areas of the United States from all past testing reached a peak value of approximately 40 picocuries of strontium-90 per gram calcium in 1964. During the period this concentration is maintained, it would lead to annual doses of about 0.03 rad in new bone and about 0.01 rad in bone marrow These values are about 6 percent of the numerical values of the RPG's for bone and bone marrow.

3. Internal exposure from cesium-137 to be taken in through the diet in the conterminous United States during the next 30 years has been estimated to be about 0.01 rad. This is about 0.2 percent of the RPG for the gonads (5 rems in 30 years averaged over the population).

4.5 The RPG's were developed for controlling normal peacetime operations assuming a condition of continuous intake and chronic exposure affecting large numbers of people for time-spans of generations. The numerical values of the RPG's do not and cannot establish a line which is safe on one side and unsafe on the other. Nevertheless, annual radiation doses from fallout equal to or greater than the numerical values of the RPG's can be used as an indication of when there is a need to initiate a careful evaluation of fallout exposures. Caution should be exercised in instituting protective actions in situations where exposures are near the numerical values of the RPG's, since the biological risks are so low that the actions could have a net adverse rather than beneficial effect on the public well-being.

4.6 The practicality and value of protective actions against widespread environmental contamination from stratospheric fallout is limited because:

1. The condition to be alleviated is chronic exposure from long-term continuous intake (10 years or more).

2. A reduction in potential intake under these conditions requires basic changes in long-term agricultural practices, food processing practices, dietary habits, or all three.

3. The actions would have to be applied on a broad enough scale to reduce the average quantity of radionuclides in the total diet from foods produced throughout large areas or the entire country.

4.7 Although the amount of fallout deposited per unit area in the Arctic is about one-fifth that deposited in 30° - 40° latitude band, a combination of ecological conditions and specific dietary habits of the Eskimos and Indians result in higher strontium and cesium body burdens than are found in the conterminous United States. The lichen-caribou (reindeer)-man pathway is the most important food chain contributing to these body burdens.

4.8 Lichens accumulate nutrients and certain other materials which are deposited directly on them from the air. Their growth is slow and they tenaciously retain the fallout materials to which they are exposed. The concentrations of cesium-137 and strontium-90 in lichens are among the highest in plant life measured anywhere in the world. These radionuclides also tend to accumulate in other persistent vegetation, such as sphagnum moss and the crowns of sedge.

4.9 Lichens are important in the diet of caribou and reindeer, particularly during the winter. Other plants such as sedges are also consumed by these animals. This diet leads to relatively high concentrations of cesium-137 and strontium-90 in the meat of these animals. High levels in the food chain can be expected to persist for several years in the arctic region. The individuals and small population groups with the highest body burdens of cesium-137 are those whose dietary preference is caribou meat. Average body burdens of cesium-137 in these inhabitants were about three times as high in 1964 as they were in 1962. People with more diversified diets have lower body burdens. In 1964 the annual dose to the Eskimos having the highest body burdens was slightly more than one-half the RPG of 3,000 nanocuries for whole body exposure of individuals in large population groups. Average doses for adults of the same village are less than one-third the RPG. Although the Federal Radiation Council did not set a specific RPG for cesium-137, in either Report No. 1 or No. 2, it did state in the Memorandum for the President (Federal Register, September 26, 1961): "The characteristics of cesium-137 lead to direct comparisons with whole body exposure for which recommendations by the Council have already been made." This implies that the RPG would be 0.5 rem* in a year to the whole body of individuals in the general population when the doses can be measured directly, or an average of 0.17 rem to a suitable sample of the population group, when direct measurement is not practicable.

*For the purposes of this report the units "rem" and "rad" are considered numerically equal.

Therefore, an annual average body burden in adults of 3,000 nanocuries and 1,000 nanocuries would be estimated to result in these respective doses. The body burdens of cesium–137 in the groups of interest are being measured directly. If a comparison with the guidance provided by the FRC is to be made, the applicable RPG is 0.5 rad per year and the corresponding annual average body burden is 3,000 nanocuries of cesium–137 in adults. Strontium-90 burdens in bone appear to be about four times as high as those found in the conterminous United States.

Conclusions

4.10 Reduction in transmission of radionuclides to man under worldwide fallout conditions could only be achieved by long–term changes in (1) agricultural practices, (2) food processing practices, or (3) basic dietary habits. Consideration of such basic economic and social changes is not warranted when annual doses from environmental contamination are comparable to the numerical value of the annual dose recommended for the RPG. It has not been possible to visualize circumstances in which the balancing of the risk of radiation against the undesirable consequences of the protective measures on social, economic, and political institutions can be reduced in advance to numerical guides for mandatory action under these circumstances.

4.11 On the basis of this information on stratospheric fallout the Council concluded that the health risk from radioactivity in food over the next several years would be too small to justify protective actions to limit the intake of radionuclides either by diet modifications or by altering the normal distribution and use of food, particularly milk and dairy products.

4.12 In view of these considerations it is recommended that:

> 5. Surveillance of the radionuclide content in food products contaminated with worldwide fallout be continued at levels appropriate to the situation.
>
> 6. Surveillance and research programs examining the special ecological situations in the arctic region continue until future trends can be predicted with greater confidence.

7. Nationwide programs to reduce potential exposure of the population from gradually increasing levels of environmental contamination, such as that associated with worldwide fallout, are not necessary now nor for future levels of fallout from past testing.

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