REPORT NO. 2

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 fordoing 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 Com mittee 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 withoutthe 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 ing 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 peace-time 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 trend6 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 formation 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 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:

(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.

<u>Derivation of Concentration Values</u>

1.24 Although concentration values should be related to appropriate RPG's, in practice they areusually 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 RRG.

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 on 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 or 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 ana 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 non-uniformity 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

assume 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 progress. It is expected that such studies will no 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 inparagraphs 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 he 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