REPORT NO. 5

background material for the development of radiation protection standards

July 1964

Staff Report of the

FEDERAL RADIATION COUNCIL

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SECTION I

INTRODUCTION

This report contains background material used in the development of guidance for Federal agencies in respect to: (1) planning protective actions to reduce potential doses to the population from radioactive fission products which may gain access to food, and (2) doses at which implementation of protective actions may be appropriate.

The material is directed to guidance concerned with protective actions affecting the normal production, processing, distribution, and use of food for human consumption when the action is taken because of the radioactive content of the food.

The first two reports of the Federal Radiation Council contained background material used in the development of guidance given in the Memorandums approved by the President on May 13, 1960, and September 13, 1961. These reports provided a general philosophy of radiation protection and general principles of control based on the annual intake of radioactive materials. The recommendations contained therein were intended to provide the basis for the control and regulation of normal peacetime operations in which exposure to radiation is a factor. Numerical values for the Radiation Protection Guides designed to limit the exposure of the whole body and certain organs as the result of normal peacetime operations were provided.

During the period of atmospheric testing of nuclear weapons in 1961 and 1962 the question arose as to the possible need for protective actions and the use of existing Radiation Protection Guides for determining the conditions under which the production, processing, distribution, and use of food, particularly fresh fluid milk, should be altered to reduce human intake of radioactive materials from fallout.

In September 1962 the Federal Radiation Council stated, in effect, that the Radiation Protection Guides provided for the conduct of normal peacetime operations are not intended to set a limit at which protective action affecting the normal production, processing, distribution, and use of food should be taken, nor to indicate what kind of action should be taken. In the 1963 hearings, "Fallout, Radiation Standards, and Countermeasures," conducted by the Joint Committee on Atomic Energy, the Council reiterated that position and noted that it would recommend to the President guidance for the appropriate Federal agencies applicable to a determination of the need for protective actions.

Scope

Limiting the exposure of members of the population to man-made radioactive material can be accomplished by controlling the release of such material from its place of origin or use, or by protecting the population after the material is released to the environment.

This report is directed to guidance for protecting the population from radioactive material after it has been released to the environment in concentrations which justify action.

Situations justifying protective action could occur from such events as: (1) an industrial accident, possibly involving a nuclear reactor or a nuclear fuel processing plant, and (2) release of radioactive materials from the detonation of nuclear weapons or other nuclear devices.

The guidance concerns protective actions which might be applied to the production, processing, distribution, or use of food to reduce the potential human intake of such radioactive material. This guidance is confined in application to those conditions under which the hazard of concern is that associated with the ingestion of radioactive materials. Conditions requiring protection from external gamma radiation or protection when inhalation may also be a significant mode of entry for radioactive material into the human body involve different considerations.

This report includes guidance as to the general principles concerned with protective actions and specific guidance applicable to iodine-131.

Preparation of the Staff Report

In the development of this report, the Staff has reviewed the literature on the origin, distribution, mechanisms of transmission through the environment, and potential biological effects of radioactive materials. In particular, the Staff has studied the transcripts of the hearings conducted by the Joint Committee on Atomic Energy; the reports by the National Committee on Radiation Protection and Measurements, the World Health Organization and Food and Agricultural Organization of the United Nations, the United Kingdom Medical Research Council's Committee on Protection against Ionizing Radiations, the National Advisory Committee on Radiation --- an advisory committee to the Surgeon General, United States Public Health Service; and the "Proceedings of the Hanford Symposium on the Biology of Radioiodine."

The Staff also has had considerable assistance from many individual scientists and technical experts.

Definitions

The absorbed dose is the energy imparted to a volume of irradiated material per unit mass of that volume.

The rad is a unit of absorbed dose equal to 100 ergs per gram.

The projected dose is the dose that would be received in the future by individuals in the population group from the contaminating event if no protective action were taken.

The Protective Action Guide (PAG) is the projected absorbed dose to individuals in the general population which warrants protective action following a contaminating event.

The curie is a unit of radioactivity defined as 3.7×10^{10} transformations per second. Commonly used multiples of the curie are the following:

1 millicurie = 1×10^{-3} curie
1 microcurie = 1×10^{-6} curie
1 nanocurie = 1×10^{-9} curie
1 picocurie = 1 micromicrocurie = 1×10^{-12} curie

SECTION II

ORIGIN AND DISTRIBUTION OF RADIOACTIVE CONTAMINATION

The origin and distribution of radioactive material injected into the atmosphere and its 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 Reports No. 3 and No. 4.

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 which 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 U.S. for the tropospheric distribution of debris from tests conducted outside the U.S.

When radioactive material is released to the atmosphere at ground level, as would generally be the case in an industrial accident, diffusion in the troposphere is limited and the passage of the radioactive cloud over an area takes a relatively short time. However, the concentrations in the cloud can be high. The deposition of radioactive materials in this case can lead to possible radiation doses that warrant protective action.

Radioactive Nuclides of Interest

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

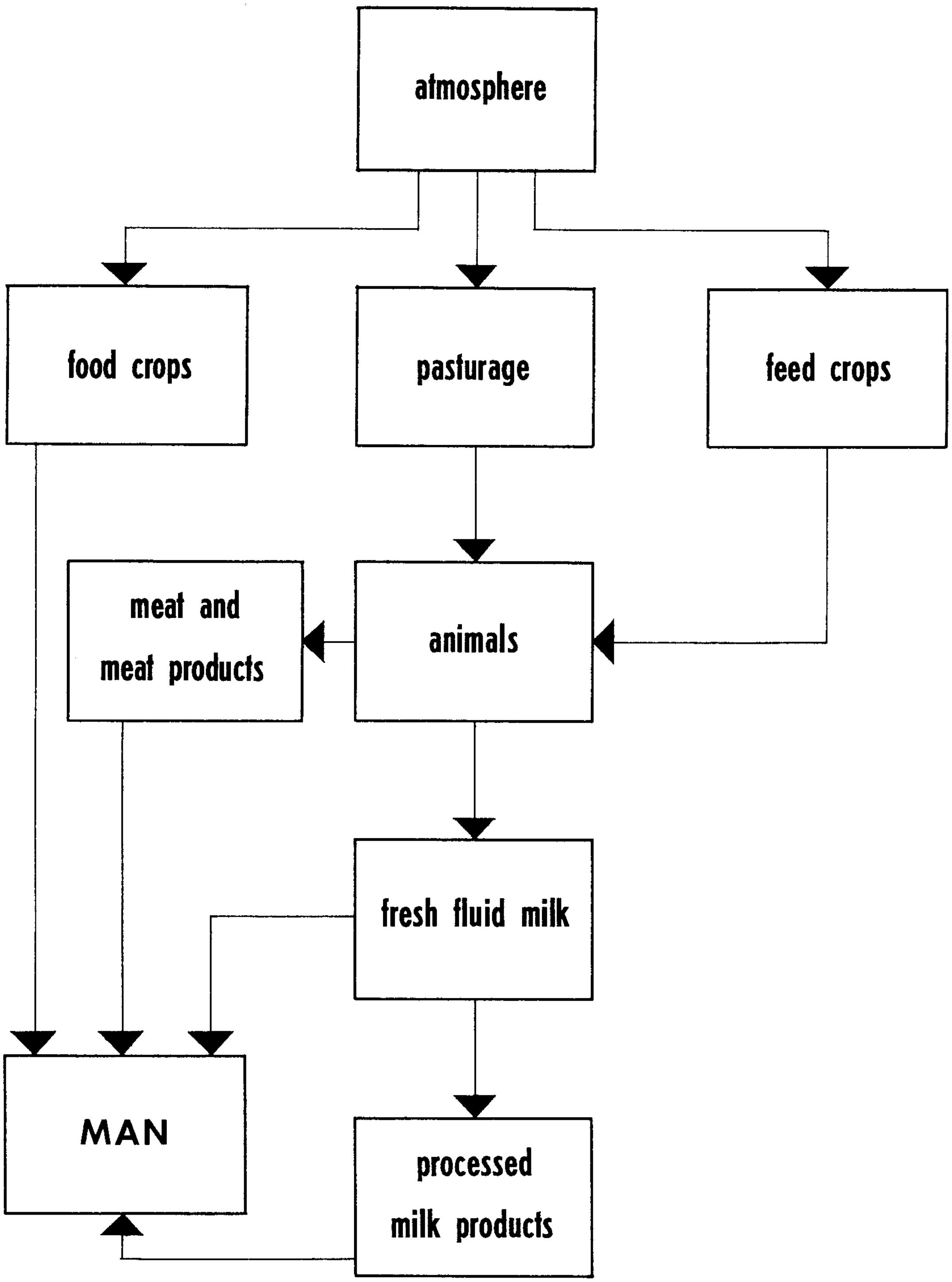
The relative importance of different radionuclides may depend on many factors such as the time that elapses between fission and the release of fission products to the environment, chemical or physical separation or fractionation, conditions of release, and season of of year. For example, in unseparated fission products only a few days of age, the properties of iodine make it the critical radionuclide, while a few weeks later the disappearance of iodine-131 will leave the longer-lived strontium-89, strontium-90, and cesium-137 as the nuclides of interest. Many studies of possible types of release important to this report have led to the conclusion that events requiring protective actions are most likely to involve iodine-131 as the critical nuclide.

The Transmission Chain

The path of radioactive material from the atmosphere through the food chain to man is shown in Figure I. The material is scavenged from the atmosphere by meteorological processes, particularly rain. If the air mass containing the radioactive material is at ground level the radionuclides may be directly removed from the air by vegetation. Following the initial deposition, the radioactive contamination tends to be removed by various processes, such as being washed off by subsequent rainfall or being blown off by the wind. The extent to which such removal occurs varies widely depending on the particle size and chemical properties of the material deposited. Although radionuclides may be incorporated subsequently into plants through absorption by the root system, their concentration on the surfaces of vegetation will be the dominant factor leading to a possible need for protective action.

FIGURE I

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



SECTION III

PROTECTIVE ACTIONS AND THEIR APPLICATIONS

A protective action, within the scope of this report, 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.

Since a protective action is taken to abate such an exposure risk after the radioactive material has been released, in the development of guidance for taking such action it is necessary to consider:

1. the possible risk to health associated with the projected dose to the population from fission products.

2. the amount by which the projected doses can be reduced by taking certain protective actions.

3. the total impact, including risks to health associated with these protective actions, and

4. the feasibility of taking the actions.

Protective actions are appropriate when the health benefit associated with the reduction in dose that can be achieved is considered sufficient to offset the undesirable factors associated with the action.

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 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.

It is possible to estimate the projected dose that will result from measured concentrations of radionuclides in the environment. This estimate is usually related to a daily or total intake of radioactive materials and can be based either on the assumption that more materials will not be added to the food chain during the period of concern, or that potential additions can be quantitatively estimated. A quantitative estimate of the projected dose is necessary for determining whether or not protective action should be taken.

Impact of Protective Actions

A decision to implement a protective action involves a comparison of the risk due to radiation exposure with the undesirable features of the contemplated action.

The impact of the protective action will involve such factors as the degree of departure from the usual practice, the length of time over which the action is applied, the relative ease with which the action can be executed, and possible health risks associated with the action.

One of the well-established actions to reduce the intake of contaminants on foods is based on the fact that they are on the surface of fresh fruits and vegetables. A large proportion of these contaminants, including radioactive material, can be removed by applying the usual practices of food preparation. The only departures from these usual practices are that: (1) more attention is given to insuring that the surfaces are washed, (2) the outer leaves of leafy vegetables are removed, and (3) more than normal preference is given to peeling.

The impact of these actions is small because they are already accepted practice and no innovations are involved. If it were required that all fruits be peeled before eating, the impact would be greater: and hence the risk would have had to be correspondingly greater to warrant this degree of intervention in accustomed activities.

Some actions, such as discarding a food item, involve a marked departure from usual practice. They may, nevertheless, be of low impact if limited to a small quantity of produce or to a small area, or if applied infrequently and only for short periods.

The feasibility of executing a protective action depends on the ease with which it can be applied by diversion of available resource factors such as the facilities, equipment, personnel, and alternative supplies of animal feeds or agricultural produce needed to implement the action. Diversion of a small fraction of readily available resources is usually easy, but diversion of a large proportion increases the impact and decreases the feasibility very rapidly. There will be very few factors, possibly only one, that are limiting in any complex of resources. These will not necessarily be the same at each place or time the protective action may be needed.

Types of Protective Actions

The types of actions to which guidance in this report may be related are:

1. Altering production, processing, or distribution practices affecting the movement of radioactive contamination through the food chain and into the human body. This action includes a storage of food and animal feed supplies to allow for the radioactive decay of short-lived nuclides.

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

3. Condemning foods.

Other possible types of action currently are judged to be less desirable for reasons of effectiveness, safety, or practicality. The use of additives in cattle rations, soil treatment, and the chemical removal of radionuclides from milk are not included among the types of actions listed.

Protective actions to reduce the intake of radioactive materials by special alterations of the normal diet are accomplished best on an individual basis under the supervision of medical authorities.

Application of Protective Actions

In providing guidance for protective actions applicable to radioactive contamination of the environment, the Council is concerned with a balance between the risk of radiation exposure and the impact on public well-being associated with the alteration of the normal production, processing, distribution, or use of food.

It is recommended that the term "Protective Action Guide" (PAG) be used to indicate the projected dose at which the above balance is judged to occur for the general types of protective actions considered in this section. Thus, the Protective Action Guide serves as a basis for deciding when such protective actions are indicated.

In the application of the Protective Action Guides 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 dose that would otherwise occur --- not to limit it to some prespecified value.

4. 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.

5. The Protective Action Guide is based on the assumption that the occurrence, in a particular area, of environmental contamination that would require protective action is an unlikely event. Circumstances that involve either repetitive occurrence or in which there appears a substantial probability of recurrence within a period of one or two years would require special consideration. In such a case the total projected dose from the several events and the total impact of the protective actions that might be taken to avoid the dose from one or more of these events must be considered. In contemplating the possibility of a future event it is necessary to consider not only the possible magnitude but also the probability that the event will occur.

6. Federal agencies should plan protective action programs designed to reduce the projected dose to individuals in the general public by modifying the normal production, processing, distribution, or use of food products or animal feeds. The need for implementing such plans should be determined on the basis of the estimated projected dose and the appropriate PAG.

SECTION IV

GUIDANCE APPLICABLE TO IODINE-131

The Environmental Pathway

The physical and biochemical characteristics of iodine-131 make it the radionuclide most likely to warrant rapid application of protective actions. This is especially true if radioactive contamination occurs before appreciable radioactive decay has taken place.

The important pathway for iodine-131 from the source to the body, and the one considered applicable to protective action criteria, is through pasture to the cow, milk, and into the human body.

The shortest time-span from source to individual occurs when fresh milk has not gone through processes of pasteurization and distribution. Iodine-131 may appear in milk a few hours after deposition on pasturage. From a single deposition it can reach a maximum concentration in milk as early as two to four days after deposition; it then decreases by half about every five days due to a combination of radioactive decay and weathering losses from grass.

Deposition of iodine-131 can vary greatly within a relatively small geographical area. As a result, there can be large differences between the iodine-131 concentrations in milk produced on farms only a few miles apart. Because of variations in deposition and in animal feeding habits, and inadequate data for evaluating the effects of these variations, it is not yet possible to predict reliably the maximum concentration of iodine-131 in milk from deposition data.

Development of the Protective Action Guide Against Iodine-131

Factors affecting the relationships between exposures of humans to iodine-131 and subsequent biological effects have been discussed in FRC Reports No. 1 and No. 2, in a report* prepared for the FRC by the National Academy of Sciences Committees on the Biological Effects of Atomic Radiation, and in the "Proceedings of the Hanford Symposium on the Biology of Radioiodine."

According to these reports, the uptake of iodine-131 in the thyroids of children and adults is approximately the same. Thus a given intake would result in a ten times larger dose to the thyroid of a one year old child (thyroid weight 2 grams) than to an adult (thyroid weight 20 grams). Children, one year of age are assumed to be the critical segment of the population.

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*Pathological Effects of Thyroid Irradiation - A report of a panel of experts from the Committees on the Biological Effects of Atomic Radiation; National Academy of Sciences; National Research Council, published by the Federal Radiation Council, July 1962.

Young children treated with X-rays in the neck region for enlarged thymus or for other benign head and neck conditions have had a significantly higher incidence of tumors, including thyroid carcinoma, than have children in control groups. Radiation doses to the thyroid found to be associated with thyroid carcinoma under these conditions range upward from about 150 rads. Experience with exposure of the thyroid to large doses of radiation from iodine-131 for therapeutic reasons is extensive but is almost entirely confined to adults. The report of the panel of experts of the NAS-NRC Committees states that, although therapeutic doses from iodine-131 to the thyroid have been in the range of a few thousand rads upward, iodine-131 has not been identified in a causative way with the development of thyroid cancer in humans, except in one doubtful case. X-ray doses to the thyroid appear to be from 5 to 15 times as effective in producing biological changes as iodine-131.

The initiation of protective action against contamination in the environment resulting from a single event (i.e., an event isolated in time from any other event that might affect the same area) involves undesirable features that may be expected to vary in importance from one circumstance to another. Of various actions that might be effective in averting the major part of the projected dose, two appear to provide the most acceptable combination of maximum effectiveness and minimum undesirable consequences. One of these is the diversion of contaminated milk to the production of dairy products that may be stored conveniently until the iodine-131 essentially has decayed, a matter of a few weeks. The other is the substitution of stored feed for pasturage until most of the iodine-131 has decayed. The choice may depend upon many factors.

Considering existing information on the biological risks associated with doses from iodine-131 and the kinds of protective action available to avert the dose from iodine-131 that has been deposited on pastures used by dairy cows, the Council has concluded that such protective action as the diversion of milk or the substitution of stored feed for pasturage to avert individual doses less than 30 rads would not usually be justifiable under the conditions considered most likely to occur. This dose is recommended as the Protective Action Guide for iodine-131.

Generally it will not be practical to estimate individual doses. In such cases decisions to take an action will be based on average values. As noted in FRC Report No. 1, paragraph 5.4, it is assumed that the majority of the individuals do not vary from the average by a factor greater than three. As an operational technique, it is considered that the PAG will not be exceeded if the average projected doses to the thyroids of a suitable sample of the population do not exceed 10 rads. A suitable sample is considered to consist of children of approximately one year of age using milk from a reasonably homogeneous supply.

The PAG is stated in terms of a projected dose; i.e., the dose that might otherwise be received if the protective action were not initiated. However, since the value of the contemplated action and, consequently, the justification of the action, depends on the dose averted, it is valid to use the projected dose as a basis for implementation of a proposed protective action only if it is expected that most of the projected dose will be averted.

Because of the differences that may exist in various circumstances it is necessary to evaluate each situation individually. It is not feasible to provide detailed criteria for taking into account differences that may occur. In general, the PAG represents the Council's judgment regarding the benefit-impact balance for the two protective actions considered acceptable and 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 protective action would be effective, initiation of such action at a projected dose higher than the PAG may be justifiable. For example, diversion of milk from fresh milk channels to processed products may be less difficult in a locality where surplus production makes allocation between the two uses a normal practice. The action would be more difficult and expensive, and the total impact would be high if the milk had to be transported large distances to a processing center, or if there were adverse effects on the quality or quantity of milk available to the consumer or adverse effects on the dietary habits of individuals in the population.

In considering the net benefit of a protective action, assuming the protective action is initiated at progressively lower values of projected dose, as the projected dose becomes less, the net benefit to public well-being from reduction of exposure becomes less.

Application of Protective Actions Against Iodine-131

The benefit of avoiding a potential dose from iodine-131 must be evaluated against the feasibility and the disadvantages of any protective action under consideration. A selected action must be feasible for the particular situation. It must not be subject to limitations such as lack of communications or transportation which would nullify its effectiveness. If warranted under certain unusual conditions, the application of protective actions in consecutive or concurrent operation may be considered. Local conditions must also be considered. For example, the proportion of fresh milk use to processed milk use in the area, or the seasonal feeding pattern for cattle may affect the efficacy of a specific protective action.

Iodine-131 concentrations may vary widely within a given milkshed. Therefore concentrations at the point of milk production must be known if efficient protective actions are to be taken. On the other hand, concentrations at the point of consumption must be known in order to evaluate the projected doses received by the population group.

Protective actions cannot attain maximum effectiveness without adequate communications. Information regarding deposition patterns and concentrations of radioiodine in milk must be obtained promptly for those groups responsible for taking protective action. The acceptance of and participation in protective actions by milk producers, processors, distributors, and consumers must be achieved. Such acceptance and participation will tend to avoid unnecessary rejection of acceptable fresh milk supplies by the public.

The specific protective actions considered in selecting the Protective Action Guide 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.

Preference for the second action may depend upon the practicability of diverting the affected milk to the production of dairy products which may be stored for several weeks before use. This does not influence the effectiveness of the action in averting a dose from iodine-131. In a sufficiently severe situation in which a more desirable alternative did not exist, it might be appropriate to substitute unaffected milk for current use with no utilization of the affected milk.

The projected future intake at any time after the maximum concentration has been reached is approximately seven times the estimated daily intake at that time, provided that additional iodine-131 is not being deposited on the pasture. If the concentration of iodine-131 in milk has passed its maximum value and is decreasing by half every five days, the relationship between the daily rate of intake at any time and the total projected subsequent intake is indicated in columns 1 and 2 of Table I.

Using the projected total intake, a projected dose for children approximately one year of age may be calculated by assuming that 30 percent of the ingested iodine is retained in a 2 gram thyroid, and by selecting an estimated value of 1 liter as the daily consumption of milk. The relationship between the total intake of iodine-131 and the projected dose is indicated in columns 2 and 3 of Table I.

A total intake of iodine-131 of 600 nanocuries would result in a dose of about 10 rads to a 2 gram thyroid. In a single event, about 20 to 25 percent of the total intake may result from the use of that portion of the milk produced before the maximum concentration was reached. Under these conditions, and if no protective action were taken, an estimated maximum concentration in milk of 60 to 70 nanocuries per liter would result in a total intake of about 600 nanocuries and a dose to the thyroid of 10 rads.

TABLE I

INTAKE OF IODINE–131 FOR DIFFERENT RADIATION DOSES TO A 2 GRAM THYROID FOLLOWING A SINGLE DEPOSITION OF IODINE–131 ON PASTURAGE [1/]

Estimated intake of iodine–131 in one day at the time of the maximum concentration or later (nanocuries)	Projected intake of iodine–131 (based on column 1) (nanocuries)	Projected thyroid dose (based on column 2) (rads)
4.2	29	.5
8.4	58	1
25	175	3
42	290	5
84	580	10
250	1750	30
1250	8750	150
2500	17500	300

[1/] This table is illustrative and does not indicate specific intake values at which protective actions should be initiated or discontinued.

The effectiveness of a protective action, if taken, will be highly dependent upon the promptness with which it is initiated. If milk from an unaffected area is to be substituted for the contaminated milk, delay of initiation of the action by as much as 10 days after the deposition occurs will reduce the total exposure that can be avoided to substantially less than half of the total exposure that would result if no action were taken. In the case of substitution of stored feed for pasturage, the same delay would reduce even further the benefit of the action because of the time required for the iodine-131 in the cow and, consequently, the concentration in the milk to decrease to negligible levels.

The exposure avoided will also depend upon the length of time the protective action is maintained. In the case of substitution of unaffected milk for contaminated milk, the reduction in the dose that would result from subsequent intake would be about 90 percent if the action were maintained for 15 to 20 days, and about 99 percent if maintained for 30 to 40 days. In the case of substitution of stored feed for pasturage, reductions would be less.

Summary

Following release of fresh fission products iodine-131 is the radionuclide considered most likely to reach concentrations in foods which warrant protective action to reduce the projected dose. The important mode of transmission to humans is through the consumption of fresh fluid milk.

Iodine-131 can appear in milk within a few hours after its deposition on pasture. The concentration in milk may reach a maximum in two to four days, after which the concentration diminishes by half about every five days.

Removal of dairy cattle from contaminated pastures or the diversion of contaminated milk to processed dairy products are recommended as protective actions to reduce human exposure from iodine-131.

The Federal Radiation Council has developed the concept of the Protective Action Guide. The PAG is defined as the projected absorbed dose to individuals in the general population which warrants protective action following a contaminating event.

A projected dose of 30 rads to the thyroid of individuals in the general population has been recommended as the Protective Action Guide for iodine-131. As an operational technique it is assumed that this condition will be met effectively if the average projected dose to a suitable sample of the population does not exceed 10 rads.

* U.S. GOVERNMENT PRINTING OFFICE : 1964 O - 752-501 PO 11