MANUAL OF PROTECTIVE ACTION GUIDES

AND

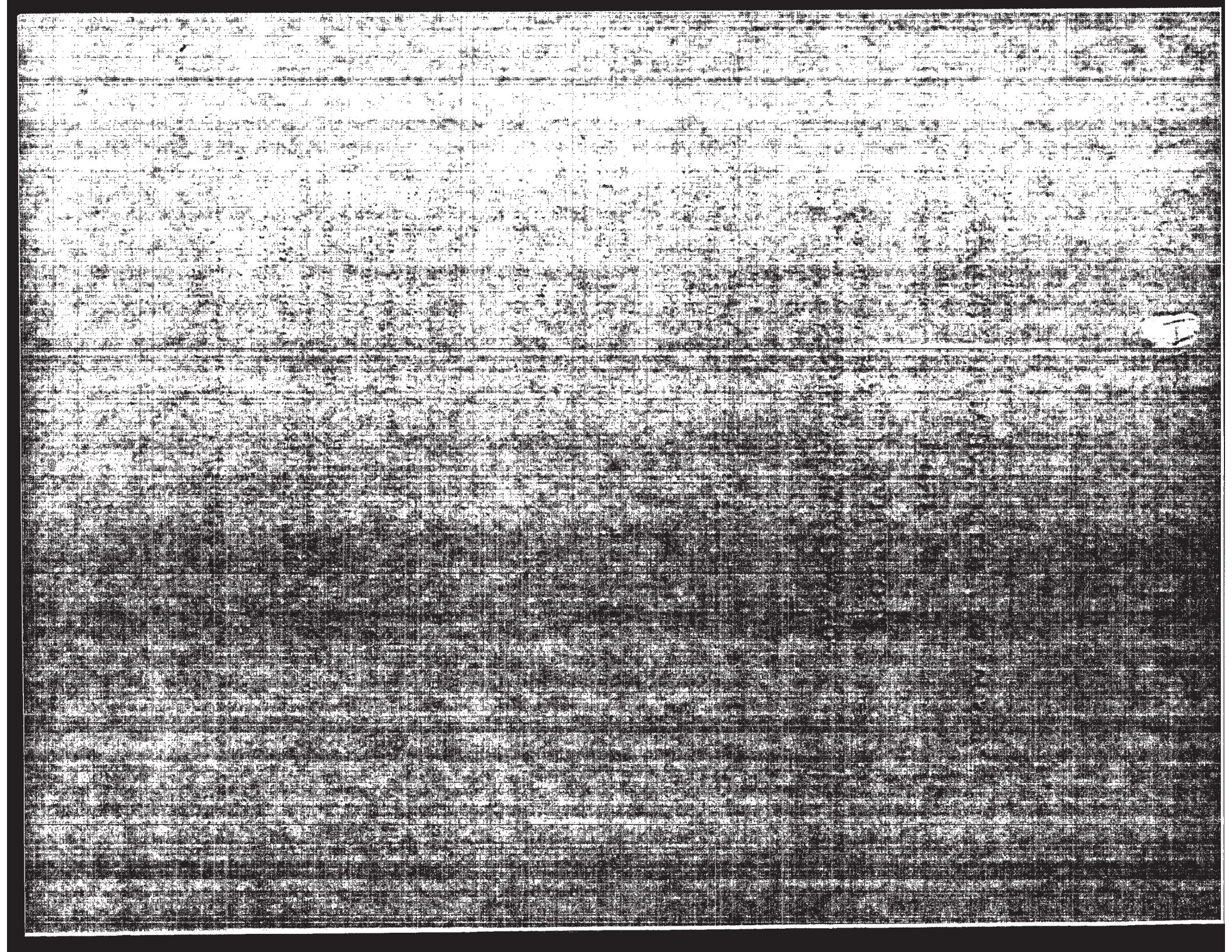
PROTECTIVE ACTIONS

FOR NUCLEAR INCIDENTS

Office of Radiation Programs
United States Environmental Protection Agency
Washington, DC 20460

Revised 1991

Second printing, May 1992



FOREWORD

Public officials are charged with the responsibility to protect the health of the public during hazardous incidents. The purpose of this manual is to assist these officials in establishing emergency response plans and in making decisions during a nuclear incident. It provides radiological protection guidance that may be used for responding to any type of nuclear incident or radiological emergency, except nuclear war.

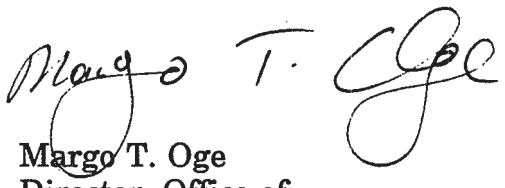
Under regulations governing radiological emergency planning and preparedness issued by the Federal Emergency Management Agency (47 FR 10758, March 11, 1982), the Environmental Protection Agency's responsibilities include, among others, (1) establishing Protective Action Guides (PAGs), (2) preparing guidance on implementing PAGs, including recommendations on protective actions, (3) developing and promulgating guidance to State and local governments on the preparation of emergency response plans, and (4) developing, implementing, and presenting training programs for State and local officials on PAGs and protective actions, radiation dose assessment, and decision making. This document is intended to respond to the first two responsibilities.

The manual begins with a general discussion of Protective Action Guides (PAGs) and their use in planning for protective actions to safeguard public health. It then presents PAGs for specific exposure pathways and associated time periods. These PAGs apply to all types of nuclear incidents. This is followed by guidance for the implementation of PAGs. Finally, appendices provide definitions, background information on health risks, and other information supporting the choice of the numerical values of the PAGs.

PAGs for protection from an airborne plume during the early phase of an incident at a nuclear power plant were published in the 1980 edition of this manual. These have now been revised to apply to a much broader range of situations and replace the PAGs formerly published in Chapters 2 and 5. Recommendations and background information for protection from ingestion of contaminated food were published by the Food and Drug Administration in 1982. These are reprinted here as Chapter 3 and Appendix D. Recommendations for PAGs for relocation are presented in Chapters 4 and 7. Additional radiation protection guidance for recovery will be developed at a later date. We are continuing work to develop PAGs for drinking water and, in cooperation with FDA, revised PAGs for food. When experience has been gained in the application of these PAGs, they will be reexamined and refined as necessary, proposed for review, and then recommended to the President as Federal radiation protection guidance.

This manual is being re-published to consolidate existing recommendations in a single volume. As revised and additional recommendations are developed, they will be issued as revisions to this manual. These revised PAGs are appropriate for incorporation into emergency response plans when they are revised or when new plans are developed. However, it is important to recognize that regulatory requirements for emergency response are not provided by this manual; they are established by the cognizant agency (e.g., the Nuclear Regulatory Commission in the case of commercial nuclear reactors, or the Department of Energy in the case of their contractor-operated nuclear facilities).

Users of this manual are encouraged to provide comments and suggestions for improving its contents. Comments should be sent to Allan C. B. Richardson, Criteria and Standards Division (ANR-460), Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, DC 20460.



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CHAPTER 1

Overview

1.0 Introduction

Public officials, in discharging their responsibility to protect the health of the public during hazardous situations, will usually be faced with decisions that must be made in a short period of time. A number of factors influencing the choice of protective actions will exist, so that the decisions may be complex. Further, all of the information needed to make the optimum choice will usually not be immediately available. In such situations, it will therefore be helpful if the complexity of the information upon which needed decisions are based can be reduced by careful planning during the formulation of emergency response plans.

The U.S. Environmental Protection Agency has developed this manual to assist public officials in planning for emergency response to nuclear incidents. In the context of this manual, a nuclear incident is defined as an event or a series of events, either deliberate or accidental, leading to the release, or potential release, into the environment of radioactive materials in sufficient quantity to warrant consideration of protective actions. (The term "incident" includes accidents, in the context of this manual.) A radiological emergency may result from an incident at a variety of types of facilities, including, but not limited to, those that are part of the nuclear fuel cycle, defense and research facilities, and facilities that produce or use radioisotopes, or from an incident connected with the transportation or use of radioactive materials at locations not classified as "facilities". This manual provides radiological protection criteria intended for application to all nuclear incidents requiring consideration of protective actions, other than nuclear war. It is designed for the use of those in Federal, State, and local government with responsibility for emergency response planning. The manual also provides guidance for implementation of the criteria. This has been developed primarily for incidents at nuclear power facilities. Although this implementation guidance is intended to be useful for application at other facilities or uses of radioactivity, emergency response plans will require the development of additional implementation procedures when physical characteristics of the radionuclides involved are different from those considered here.

The decision to advise members of the public to take an action to protect themselves from radiation from a nuclear incident involves a complex judgment in which the risk avoided by the protective action must be weighed in the context of the risks involved in taking the action. Furthermore, the

decision may have to be made under emergency conditions, with little or no detailed information available. Therefore, considerable planning is necessary to reduce to a manageable level the complexity of decisions required to effectively protect the public at the time of an incident.

An objective of emergency planning is to simplify the choice of possible responses so that judgments are required only for viable and useful alternatives when an emergency occurs. During the planning process it is possible to make some value judgments and to determine which responses are not required, which decisions can be made on the basis of prior judgments, and which judgments must be made during an actual emergency. From this exercise, it is then possible to devise operational plans which can be used to respond to the spectrum of hazardous situations which may develop.

The main contribution to the protection of the public from abnormal releases of radioactive material is provided by site selection, design, quality assurance in construction, engineered safety systems, and the competence of staff in safe operation and maintenance. These measures can reduce both the probability and the magnitude of potential consequences of an accident. Despite these measures, the occurrence of nuclear incidents cannot be excluded. Accordingly, emergency response planning to mitigate the consequences of an incident is a necessary supplementary level of protection.

During a nuclear incident, when the source of exposure of the public is not under control, the public usually can be protected only by some form of intervention which will disrupt normal living. Such intervention is termed protective action. A Protective Action Guide (PAG) is the projected dose to reference man, or other defined individual, from an unplanned release of radioactive material at which a specific protective action to reduce or avoid that dose is recommended. The objective of this manual is to provide such PAGs for the principal protective actions available to public officials during a nuclear incident, and to provide guidance for their use.

1.1 Nuclear Incident Phases and Protective Actions

It is convenient to identify three time phases which are generally accepted as being common to all nuclear incident sequences; within each, different considerations apply to most protective actions. These are termed the early, intermediate, and late phases. Although these phases cannot be represented by precise periods and may overlap, they provide a useful framework for the considerations involved in emergency response planning.

The early phase (also referred to as the emergency phase) is the period at the beginning of a nuclear incident when immediate decisions for effective use of protective actions are required and must therefore usually be based primarily on the status of the nuclear

facility (or other incident site) and the prognosis for worsening conditions. When available, predictions of radiological conditions in the environment based on the condition of the source or actual environmental measurements may also be used. Protective actions based on the PAGs may be preceded by precautionary actions during this period. This phase may last from hours to days.

The intermediate phase is the period beginning after the source and releases have been brought under control and reliable environmental measurements are available for use as a basis for decisions on additional protective actions. It extends until these additional protective actions are terminated. This phase may overlap the early and late phase and may last from weeks to many months.

The late phase (also referred to as the recovery phase) is the period beginning when recovery action designed to reduce radiation levels in the environment to acceptable levels for unrestricted use are commenced, and ending when all recovery actions have been completed. This period may extend from months to years.

The protective actions available to avoid or reduce radiation dose can be categorized as a function of exposure pathway and incident phase, as shown in Table 1-1. Evacuation and sheltering (supplemented by bathing and changes of clothing), are the principal protective actions for use during the early phase to protect the public from exposure to direct radiation and inhalation from an airborne plume. It may also be appropriate to initiate protective action for the milk supply during this period, and, in cases where emergency response plans include procedures for issuing stable iodine to reduce thyroid dose (FE-85), this may be an appropriate protective action for the early phase.

Some protective actions are not addressed by assignment of a PAG. For example, the control of access to areas is a protective action whose introduction is coupled to a decision to implement one of the other early or intermediate phase protective actions and does not have a separate PAG. And, although the use of simple, ad hoc respiratory protection may be applicable for supplementary protection in some circumstances, this protective action is primarily for use by emergency workers.

There are two types of protective actions during the intermediate phase. First, relocation and decontamination are the principal protective actions for protection of the public from whole body external exposure due to deposited material and from inhalation of any resuspended radioactive particulate materials during the intermediate and late phases. It is assumed that decisions will be made during the intermediate phase concerning whether areas from which the public has been relocated will be decontaminated and reoccupied, or condemned and the occupants permanently relocated. The second major type of protective action during the intermediate phase encompasses

TABLE 1-1. EXPOSURE PATHWAYS, INCIDENT PHASES, AND PROTECTIVE ACTIONS.

POTENTIAL EXPOSURE PATHWAYS AND INCIDENT PHASES		PROTECTIVE ACTIONS
1. External radiation from facility	*Early*	Sheltering Evacuation Control of access
2. External radiation from plume	*Early*	Sheltering Evacuation Control of access
3. Inhalation of activity in plume	*Early*	Sheltering Administration of stable iodine Evacuation Control of access
4. Contamination of skin and clothes	*Early* / *Intermediate*	Sheltering Evacuation Decontamination of persons
5. External radiation from ground deposition of activity	*Intermediate* / *Late*	Evacuation Relocation Decontamination of land and property
6. Ingestion of contaminated food and water	*Intermediate* / *Late*	Food and water controls
7. Inhalation of resuspended activity	*Intermediate* / *Late*	Relocation Decontamination of land and property

Note: The use of stored animal feed and uncontaminated water to limit the uptake of radionuclides by domestic animals in the food chain can be applicable in any of the phases.

restrictions on the use of contaminated food and water. This protective action, in particular, may overlap the early and late phases.

It is necessary to distinguish between evacuation and relocation with regard to incident phases. Evacuation is the urgent removal of people from an area to avoid or reduce high-level, short-term exposure, usually from the plume or deposited activity. Relocation, on the other hand, is the removal or continued exclusion of people (households) from contaminated areas to avoid chronic radiation exposure. Conditions may develop in which some groups who have been evacuated in an emergency may be allowed to return based on the relocation PAGs, while others may be converted to relocation status.

1.2 Basis for Selecting Protective Action Guides

The PAGs in this manual incorporate the concepts and guidance contained in Federal Radiation Council (FRC) Reports 5 and 7 (FR-64 and FR-65). One of these is that the decision to implement protective actions should be based on the projected dose that would be received if the protective actions were not implemented. However, since these reports were issued, considerable additional guidance has been developed on the subject of emergency response (IC-84, IA-89). EPA considered the following four principles in establishing values for the PAGs:

1. Acute effects on health (those that would be observable within a short period of time and which have a dose threshold below which such effects are not likely to occur) should be avoided.

2. The risk of delayed effects on health (primarily cancer and genetic effects for which linear nonthreshold relationships to dose are assumed) should not exceed upper bounds that are judged to be adequately protective of public health under emergency conditions, and are reasonably achievable.

3. PAGs should not be higher than justified on the basis of optimization of cost and the collective risk of effects on health. That is, any reduction of risk to public health achievable at acceptable cost should be carried out.

4. Regardless of the above principles, the risk to health from a protective action should not itself exceed the risk to health from the dose that would be avoided.

The above principles apply to the selection of any PAG. Principles 1, 3, and 4 have been proposed for use by the international community as essential bases for decisions to intervene during an incident and Principle 2 has been recognized as an appropriate additional consideration (IA-89). Appendices C and E apply these principles to the choice of PAGs for evacuation and relocation. Although in establishing the PAGs it is prudent to consider a range of source terms to assess the costs associated with their implementation, the PAGs

are chosen so as to be independent of the magnitude or type of release.

1.3 Planning

The planning elements for developing radiological emergency response plans for nuclear incidents at commercial nuclear power facilities are provided in a separate document, NUREG-0654 (NR-80), which references the PAGs in this Manual as the basis for emergency response. Planning elements for other types of nuclear incidents should be developed using similar types of considerations.

Similarly, guidance for nuclear power facilities on time frames for response, the types of releases to be considered, emergency planning zones (EPZ), and the potential effectiveness of various protective actions is provided in NUREG-0396 (NR-78). The size and shape of the recommended EPZs were only partially based on consideration of the numerical values of the PAGs. A principle additional basis was that the planning zone for evacuation and sheltering should be large enough to accommodate any urban and rural areas affected and involve the various organizations needed for emergency response. This consideration is appropriate for any facility requiring an emergency response plan involving offsite areas. Experience gained through emergency response exercises is then expected to provide an adequate basis for expanding the response to an actual incident to larger areas, if needed. It is also noted that the 10-mile radius EPZ for the early phase is large enough to avoid exceeding the PAGs for the early phase at its boundary for low-consequence, nuclear reactor, core-melt accidents and to avoid early fatalities for high-consequence, nuclear reactor core-melt accidents. The 50-mile EPZ for ingestion pathways was selected to account for the proportionately higher doses via ingestion compared to inhalation and whole body external exposure pathways.

1.4 Implementation of Protective Actions

The sequence of events during the early phase includes evaluation of conditions at the location of the incident, notification of responsible authorities, prediction or evaluation of potential consequences to the general public, recommendations for action, and implementing protection of the public. In the early phase of response, the time available to implement the most effective protective actions may be limited.

Immediately upon becoming aware that an incident has occurred that may result in exposure of the population, responsible authorities should make a preliminary evaluation to determine the nature and potential magnitude of the incident. This evaluation should determine whether conditions indicate a significant possibility of a major release and, to the extent feasible, determine potential exposure pathways, populations at risk, and projected doses. The incident evaluation and recommendations should

then be presented to emergency response authorities for action. In the absence of recommendations for protective actions in specific areas from the official responsible for the source, the emergency plan should, where practicable, provide for protective action in predesignated areas.

Contrary to the usual situation during the early phase, dose projections used to support protective action decisions during the intermediate and late phases will be based on measurements of environmental radioactivity and dose models. Following relocation of the public from affected areas to protect them from exposure to deposited materials, it will also be necessary to compile radiological and cost of decontamination data to form the basis for radiation protection decisions for recovery.

The PAGs do not imply an acceptable level of risk for normal (nonemergency conditions). They also do not represent the boundary between safe and unsafe conditions, rather, they are the approximate levels at which the associated protective actions are justified. Furthermore, under emergency conditions, in addition to the protective actions specifically identified for application of PAGs, any other reasonable measures available should be taken to minimize radiation exposure of the general public and of emergency workers.

References

FE-85 Federal Emergency Management Agency. Federal Policy on Distribution of Potassium Iodide around Nuclear Power Sites for Use as a Thyroidal Blocking Agent. Federal Register, 50, 30256; July 24, 1985.

FR-64 Federal Radiation Council. Radiation Protection Guidance for Federal Agencies. Federal Register, 29, 12056-7; August 22, 1965.

FR-65 Federal Radiation Council. Radiation Protection Guidance for Federal Agencies. Federal Register, 30, 6953-5; May 22, 1965.

IA-89 International Atomic Energy Agency. Principles for Establishing Intervention Levels for the Protection of the Public in the Event of a Nuclear Accident or Radiological Emergency. Safety Series No. 72, revision 1, International Atomic Energy Agency, Vienna (1991).

IC-84 International Commission on Radiological Protection. Protection of the Public in the Event of Major Radiation Accidents: Principles for Planning, ICRP Publication 40, Pergamon Press, Oxford (1984).

NR-78 Nuclear Regulatory Commission. Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants, U.S. Nuclear Regulatory Commission, Washington (1978).

NR-80 Nuclear Regulatory Commission. Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants. U.S. Nuclear Regulatory Commission, Washington (1980).

CHAPTER 2

Protective Action Guides for the Early Phase of an Atmospheric Release

2.1 Introduction

Rapid action may be needed to protect members of the public during an incident involving a large release of radioactive materials to the atmosphere. This chapter identifies the levels of exposure to radiation at which such prompt protective action should be initiated. These are set forth as Protective Action Guides (PAGs) for the general population. Guidance for limiting exposure of workers during such an incident is also provided. This guidance applies to any type of nuclear accident or other incident (except nuclear war) that can result in exposure of the public to an airborne release of radioactive materials.

In the case of an airborne release the principal relevant protective actions are evacuation or sheltering. These may be supplemented by additional actions such as washing and changing clothing or by using stable iodine to partially block uptake of radioiodine by the thyroid.

The former Federal Radiation Council (FRC), in a series of recommendations issued in the 1960's, introduced the concept of PAGs and issued guides for avoidance of exposure due to ingestion of strontium-89, strontium-90, cesium-137, and iodine-131. Those guides were developed for the case of worldwide atmospheric fallout from weapons testing, and are appropriate for application to intake due to long term contamination from such atmospheric releases. That is, they were not developed for protective actions relevant to prompt exposure to an airborne release from a fixed facility. The guidance in this chapter thus does not supersede this previous FRC guidance, but provides new guidance for different exposure pathways and situations.

2.1.1 Applicability

These PAGs are expected to be used for planning purposes: for example, to develop radiological emergency response plans and to exercise those plans. They provide guidance for response decisions and should not be regarded as dose limits. During a real incident, because of characteristics of the incident and local conditions that cannot be anticipated, professional judgment will be required in their application. Situations could occur, for example, in which a nuclear incident happens when environmental conditions or other constraints make evacuation impracticable. In these situations, sheltering may be the

protective action of choice, even at projected doses above the PAG for evacuation. Conversely, in some cases evacuation may be useful at projected doses below the PAGs. Each case will require judgments by those responsible for decisions on protective actions at the time of an incident.

The PAGs are intended for general use to protect all of the individuals in an exposed population. To avoid social and family disruption and the complexity of implementing different PAGs for different groups under emergency conditions, the PAGs should be applied equally to most members of the population. However, there are some population groups that are at markedly different levels of risk from some protective actions -- particularly evacuation. Evacuation at higher values is appropriate for a few groups for whom the risk associated with evacuation is exceptionally high (e.g., the infirm who are not readily mobile), and the PAGs provide for this.

Some incidents may occur under circumstances in which protective actions cannot be implemented prior to a release (e.g., transportation incidents). Other incidents may involve only slow, small releases over an extended period, so that the urgency is reduced and protective action may be more appropriately treated as relocation (see Chapter 4) than as evacuation. Careful judgment will be needed to decide whether or not to apply these PAGs for the early phase under such circumstances.

The PAGs do not imply an acceptable level of risk for normal (nonemergency) conditions. PAGs also do not represent the boundary between safe and unsafe conditions; rather, they are the approximate levels at which the associated protective actions are justified. Furthermore, under emergency conditions, in addition to the protective actions specifically identified, any other reasonable measures available should be taken to reduce radiation exposure of the general public and of emergency workers. These PAGs are not intended for use as criteria for the ingestion of contaminated food or water, for relocation, or for return to an area contaminated by radioactivity. Separate guidance is provided for these situations in Chapters 3 and 4.

2.1.2 Emergency Planning Zones and the PAGs

For the purpose of identifying the size of the planning area needed to establish and test radiological emergency response plans, emergency planning zones (EPZs) are typically specified around nuclear facilities. There has been some confusion among emergency planners between these EPZs and the areas potentially affected by protective actions. It is not appropriate to use the maximum distance where a PAG might be exceeded as the basis for establishing the boundary of the EPZ for a facility. For example, the choice of EPZs for commercial nuclear power facilities has been based, primarily, on consideration of the area needed to assure an

adequate planning basis for local response functions and the area in which acute health effects could occur.[1] These considerations will also be appropriate for use in selecting EPZs for most other nuclear facilities. However, since it will usually not be necessary to have offsite planning if PAGs cannot be exceeded offsite, EPZs need not be established for such cases.

2.1.3 Incident Phase

The period addressed by this chapter is denoted the "early phase." This is somewhat arbitrarily defined as the period beginning at the projected (or actual) initiation of a release and extending to a few days later, when deposition of airborne materials has ceased and enough information has become available to permit reliable decisions about the need for longer term protection. During the early phase of an incident doses may accrue both from airborne and from deposited radioactive materials. Since the dose to persons who are not evacuated will continue until relocation can be implemented (if it is necessary), it is appropriate to include in the early phase the total dose that will be received prior to such relocation. For the purpose of planning, it will usually be convenient to assume that the early phase will last for four days -- that is, that the duration of the primary release is less than four days, and that exposure to deposited materials after four days can be addressed through other protective actions, such as relocation, if this is warranted. (Because of the unique characteristics of some facilities or situations, different time periods may be more appropriate for planning purposes, with corresponding modification of the dose conversion factors cited in Chapter 5.)

2.2 Exposure Pathways

The PAGs for members of the public specified in this chapter refer only to doses incurred during the early phase. These may include external gamma dose and beta dose to the skin from direct exposure to airborne materials and from deposited materials, and the committed dose to internal organs from inhalation of radioactive material. Exposure pathways that make only a small contribution (e.g., less than about 10 percent) to the dose incurred in the early phase need not be considered. Inhalation of resuspended particulate materials will, for example, generally fall into this category.

Individuals exposed to a plume may also be exposed to deposited material over longer periods of time via ingestion, direct external exposure, and inhalation pathways. Because it is

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[1]The development of EPZs for nuclear power facilities is discussed in the 1978 NRC/EPA document "Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants" NUREG-0396. EPZs for these facilities have typically been chosen to have a radius of approximately 10 miles for planning evacuation and sheltering and a radius of approximately 50 miles for planning protection from ingestion of contaminated foods.

usually not practicable, at the time of an incident, to project these long-term doses and because different protective actions may be appropriate, these doses are not included in the dose specified in the PAGs for the early phase. Such doses are addressed by the PAGs for the intermediate phase (see Chapters 3 and 4).

The first exposure pathway from an accidental airborne release of radioactive material will often be direct exposure to an overhead plume of radioactive material carried by winds. The detailed content of such a plume will depend on the source involved and conditions of the incident. For example, in the case of an incident at a nuclear power reactor, it would most commonly contain radioactive noble gases, but may also contain radioiodines and radioactive particulate materials. Many of the these materials emit gamma radiation which can expose people nearby, as the plume passes. In the case of some other types of incidents, particularly those involving releases of alpha emitting particulate materials, direct exposure to gamma radiation is not likely to be the most important pathway.

A second exposure pathway occurs when people are directly immersed in a radioactive plume, in which case radioactive material is inhaled (and the skin and clothes may also become contaminated), e.g., when particulate materials or radioiodines are present. When this occurs, internal body organs as well as the skin may be exposed. Although exposure from materials deposited on the skin and clothing could be significant, generally it will be less important than that from radioactive material taken into the body through inhalation. This is especially true if early protective actions include washing exposed skin and changing clothing. Inhaled radioactive particulate materials, depending on their solubility in body fluids, may remain in the lungs or move via the bloodstream to other organs, prior to elimination from the body. Some radionuclides, once in the bloodstream, are concentrated in a single body organ, with only small amounts going to other organs. For example, if radioiodines are inhaled, a significant fraction moves rapidly through the bloodstream to the thyroid gland.

As the passage of a radioactive plume containing particulate material and/or radioiodine progresses, some of these materials will deposit onto the ground and other surfaces and create a third exposure pathway. People present after the plume has passed will receive exposure from gamma and beta radiation emitted from these deposited materials. If large quantities of radioiodines or gamma-emitting particulate materials are contained in a release, this exposure pathway, over a long period, can be more significant than direct exposure to gamma radiation from the passing plume.

2.3 The Protective Action Guides

The PAGs for response during the early phase of an incident are summarized in Table 2-1. The PAG for

evacuation (or, as an alternative in certain cases, sheltering) is expressed in terms of the projected sum of the effective dose equivalent from external radiation and the committed effective dose equivalent incurred from inhalation of radioactive materials from exposure and intake during the early phase. (Further references to dose to members of the public in this Chapter refer to this definition, unless otherwise specified.) Supplementary guides are specified in terms of committed dose equivalent to the thyroid and dose equivalent to the skin. The PAG for the administration of stable iodine is specified in terms of the committed dose equivalent to the thyroid from radioiodine. This more complete guidance updates and replaces previous values, expressed in terms of whole-body dose equivalent from external gamma exposure and thyroid dose equivalent from inhalation of radioactive iodines, that were recommended in the 1980 edition of this document.

2.3.1 Evacuation and Sheltering

The basis for the PAGs is given in Appendix C. In summary, this analysis indicates that evacuation of the public will usually be justified when the projected dose to an individual is one rem. This conclusion is based primarily on EPA's judgment concerning acceptable levels of risk of effects on public health from radiation exposure in an emergency situation. The analysis also shows that, at this radiation dose, the risk avoided is usually much greater than the risk from evacuation itself. However, EPA recognizes the uncertainties associated with quantifying risks associated with these levels of radiation exposure, as well as the variability of risks associated with evacuation under differing conditions.

Some judgment will be necessary when considering the types of protective actions to be implemented and at what levels in an emergency situation. Although the PAG is expressed as a range of 1-5 rem, it is emphasized that, under normal conditions, evacuation of members of the general population should be initiated for most incidents at a projected dose of 1 rem. (It should be recognized that doses to some individuals may exceed 1 rem, even if protective actions are initiated within this guidance.) It is also possible that conditions may exist at specific facilities which warrant consideration of values other than those recommended for general use here.[3]

Sheltering may be preferable to evacuation as a protective action in some situations. Because of the higher risk associated with evacuation of some special groups in the population (e.g. those who are not readily mobile), sheltering may be the preferred alternative for such groups as a

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[3]EPA, in accordance with its responsibilities under the regulations governing radiological emergency planning (47FR10758; March 11, 1982) and under the Federal Radiological Emergency Response Plan, will consult with Federal agencies and the States, as requested, in such cases.

Table 2-1 PAGs for the Early Phase of a Nuclear Incident

Protective Action	PAG (projected dose)	Comments
Evacuation (or sheltering[a])	1-5 rem[b]	Evacuation (or, for some situations, sheltering[a]) should normally be initiated at 1 rem. Further guidance is provided in Section 2.3.1
Administration of stable iodine	25 rem[c]	Requires approval of State medical officials.

[a]Sheltering may be the preferred protective action when it will provide protection equal to or greater than evacuation, based on consideration of factors such as source term characteristics, and temporal or other site-specific conditions (see Section 2.3.1).

[b]The sum of the effective dose equivalent resulting from exposure to external sources and the committed effective dose equivalent incurred from all significant inhalation pathways during the early phase. Committed dose equivalents to the thyroid and to the skin may be 5 and 50 times larger, respectively.

[c]Committed dose equivalent to the thyroid from radioiodine.

protective action at projected doses up to 5 rem. In addition, under unusually hazardous environmental conditions use of sheltering at projected doses up to 5 rem to the general population (and up to 10 rem to special groups) may become justified. Sheltering may also provide protection equal to or greater than evacuation due to the nature of the source term and/or in the presence of temporal or other site-specific conditions. Illustrative examples of situations or groups for which evacuation may not be appropriate at 1 rem include: a) the presence of severe weather, b) competing disasters, c) institutionalized persons who are not readily mobile, and d) local physical factors which impede evacuation. Examples of situations or groups for which evacuation at 1 rem normally would be appropriate include: a) an

incident which occurs at night, b) an incident which occurs when children are in school, and c) institutionalized persons who are readily mobile. Evacuation seldom will be justified at less than 1 rem. The examples described above regarding selection of the most appropriate protective action are intended to be illustrative and not exhaustive. In general, sheltering should be preferred to evacuation whenever it provides equal or greater protection.

No specific minimum level is established for initiation of sheltering. Sheltering in place is a low-cost, low-risk protective action that can provide protection with an efficiency ranging from zero to almost 100 percent, depending on the circumstances. It can also be particularly useful to assure that a population is positioned so that, if the need arises, communication with the population can be carried out expeditiously. For the above reasons, planners and decision makers should consider implementing sheltering at projected doses below 1 rem; however, implementing protective actions for projected doses at very low levels would not be reasonable (e.g. below 0.1 rem). (This guidance should not be construed as establishing an additional lower level PAG for sheltering.) Sheltering should always be implemented in cases when evacuation is not carried out at projected doses of 1 rem or more.

Analyses for some hypothesized accidents, such as short-term releases of transuranic materials, show that sheltering in residences and other buildings can be highly effective at reducing dose, may provide adequate protection, and may be more effective than evacuation when evacuation cannot be completed before plume arrival (DO-90). However, reliance on large dose reduction factors for sheltering should be accompanied by cautious examination of possible failure mechanisms, and, except in very unusual circumstances, should never be relied upon at projected doses greater than 10 rem. Such analyses should be based on realistic or "best estimate" dose models and include unavoidable dose during evacuation. Sheltering and evacuation are discussed in more detail in Section 5.5.

2.3.2 Thyroid and Skin Protection

Since the thyroid is at disproportionately high risk for induction of nonfatal cancer and nodules, compared to other internal organs, additional guidance is provided to limit the risk of these effects (see footnote to Table 2-1). In addition, effective dose, the quantity used to express the PAG, encompasses only the risk of fatal cancer from irradiation of organs within the body, and does not include dose to skin. Guidance is also provided, therefore, to protect against the risk of skin cancer (see Table 2-1, footnote b).

The use of stable iodine to protect against uptake of inhaled radioiodine by the thyroid is recognized as an effective alternative to evacuation for situations involving radioiodine releases when evacuation cannot be

implemented or exposure occurs during evacuation. Stable iodine is most effective when administered immediately prior to exposure to radioiodine. However, significant blockage of the thyroid dose can be provided by administration within one or two hours after uptake of radioiodine. If the administration of stable iodine is included in an emergency response plan, its use may be considered for exposure situations in which the committed dose equivalent to the thyroid can be 25 rem or greater (see 47 FR 28158; June 29, 1982).

Washing and changing of clothing is recommended primarily to provide protection from beta radiation from radioiodines and particulate materials deposited on the skin or clothing. Calculations indicate that dose to skin should seldom, if ever, be a controlling pathway. However, it is good radiation protection practice to recommend these actions, even for alpha-emitting radioactive materials, as soon as practical for persons significantly exposed to a contaminating plume (i.e., when the projected dose from inhalation would have justified evacuation of the public under normal conditions).

2.4 Dose Projection

The PAGs are expressed in terms of projected dose. However, in the early phase of an incident (either at a nuclear facility or other accident site), parameters other than projected dose may frequently provide a more appropriate basis for decisions to implement protective actions. When a facility is operating outside its design basis, or an incident is imminent but has not yet occurred, data adequate to directly estimate the projected dose may not be available. For such cases, provision should be made during the planning stage for decisions to be made based on specific conditions at the source of a possible release that are relatable to ranges of anticipated offsite consequences. Emergency response plans for facilities should make use of Emergency Action Levels (EALs)[4], based on in-plant conditions, to trigger notification of and recommendations to offsite officials to implement prompt evacuation or sheltering in specified areas in the absence of information on actual releases or environmental measurements. Later, when these data become available, dose projections based on measurements may be used, in addition to plant conditions, as the basis for implementing further protective actions. (Exceptions may occur at sites with large exclusion areas where some field and source data may be available in sufficient time for protective action decisions to be based on environmental measurements.) In the case of transportation accidents or other incidents that are not related to a facility, it will often not be practicable to establish EALs.

The calculation of projected doses should be based on realistic dose

[4]Emergency Action Levels related to plant conditions at commercial nuclear power plants are discussed in Appendix 1 to NUREG-0654 (NR-80).

models, to the extent practicable. Doses incurred prior to initiation of a protective action should not normally be included. Similarly, doses that might be received following the early phase should not be included for decisions on whether or not to evacuate or shelter. Such doses, which may occur from food and water, long-term radiation exposure to deposited radioactive materials, or long-term inhalation of resuspended materials, are chronic exposures for which neither emergency evacuation nor sheltering are appropriate protective actions. Separate PAGs relate the appropriate protective action decisions to those exposure pathways (Chapter 4). As noted earlier, the projection of doses in the early phase need include only those exposure pathways that contribute a significant fraction (e.g., more than about 10 percent) of the dose to an individual.

In practical applications, dose projection will usually begin at the time of the anticipated (or actual) initiation of a release. For those situations where significant dose has already occurred prior to implementing protective action, the projected dose for comparison to a PAG should not include this prior dose.

2.5 Guidance for Controlling Doses to Workers Under Emergency Conditions

The PAGs for protection of the general population and dose limits for workers performing emergency services are derived under different assumptions. PAGs consider the risks to individuals, themselves, from exposure to radiation, and the risks and costs associated with a specific protective action. On the other hand, workers may receive exposure under a variety of circumstances in order to assure protection of others and of valuable property. These exposures will be justified if the maximum risks permitted to workers are acceptably low, and the risks or costs to others that are avoided by their actions outweigh the risks to which workers are subjected.

Workers who may incur increased levels of exposure under emergency conditions may include those employed in law enforcement, fire fighting, radiation protection, civil defense, traffic control, health services, environmental monitoring, transportation services, and animal care. In addition, selected workers at institutional, utility, and industrial facilities, and at farms and other agribusiness may be required to protect others, or to protect valuable property during an emergency. The above are examples - not designations - of workers that may be exposed to radiation under emergency conditions.

Guidance on dose limits for workers performing emergency services is summarized in Table 2-2. These limits apply to doses incurred over the duration of an emergency. That is, in contrast to the PAGs, where only the future dose that can be avoided by a specific protective action is considered, all doses received during an emergency are included in the limit. Further, the dose to workers performing emergency

Table 2-2 Guidance on Dose Limits for Workers Performing Emergency Services

Dose limit[a] (rem)	Activity	Condition
5	all	
10	protecting valuable property	lower dose not practicable
25	life saving or protection of large populations	lower dose not practicable
>25	lifesaving or protection of large populations	only on a voluntary basis to persons fully aware of the risks involved (See Tables 2-3 and 2-4)

[a]Sum of external effective dose equivalent and committed effective dose equivalent to nonpregnant adults from exposure and intake during an emergency situation. Workers performing services during emergencies should limit dose to the lens of the eye to three times the listed value and doses to any other organ (including skin and body extremities) to ten times the listed value. These limits apply to all doses from an incident, except those received in unrestricted areas as members of the public during the intermediate phase of the incident (see Chapters 3 and 4).

services may be treated as a once-in-a-lifetime exposure, and not added to occupational exposure accumulated under nonemergency conditions for the purpose of ascertaining conformance to normal occupational limits, if this is necessary. However, any radiation exposure of workers that is associated with an incident, but accrued during nonemergency operations, should be limited in accordance with relevant occupational limits for normal situations. Federal Radiation Protection Guidance for occupational exposure recommends an upper bound of five rem per year for adults and one tenth this value for minors and the unborn (EP-87). We recommend use of this same value here for the case of exposures during an emergency. To assure adequate protection of minors and the unborn during emergencies, the performance of emergency services should be limited to nonpregnant adults. As in the case of normal occupational exposure, doses received under emergency conditions should also be maintained as low as reasonably achievable (e.g., use of stable iodine, where appropriate, as a prophylaxis to

reduce thyroid dose from inhalation of radioiodines and use of rotation of workers).

Doses to all workers during emergencies should, to the extent practicable, be limited to 5 rem. There are some emergency situations, however, for which higher exposure limits may be justified. Justification of any such exposure must include the presence of conditions that prevent the rotation of workers or other commonly-used dose reduction methods. Except as noted below, the dose resulting from such emergency exposure should be limited to 10 rem for protecting valuable property, and to 25 rem for life saving activities and the protection of large populations. In the context of this guidance, exposure of workers that is incurred for the protection of large populations may be considered justified for situations in which the collective dose avoided by the emergency operation is significantly larger than that incurred by the workers involved.

Situations may also rarely occur in which a dose in excess of 25 rem for emergency exposure would be unavoidable in order to carry out a lifesaving operation or to avoid extensive exposure of large populations. It is not possible to prejudge the risk that one should be allowed to take to save the lives of others. However, persons undertaking any emergency operation in which the dose will exceed 25 rem to the whole body should do so only on a voluntary basis and with full awareness of the risks involved, including the numerical levels of dose at which acute effects of radiation will be incurred and numerical estimates of the risk of delayed effects.

Tables 2-3 and 2-4 provide some general information that may be useful in advising emergency workers of risks of acute and delayed health effects associated with large doses of radiation. Table 2-3 presents estimated risks of early fatalities and moderately severe prodromal (forewarning) effects that are likely to occur shortly after exposure to a wide range of whole body radiation doses. Estimated average cancer mortality risks for emergency workers corresponding to a whole-body dose equivalent of 25 rem are given in Table 2-4, as a function of age at the time of exposure. To estimate average cancer mortality for moderately higher doses the results in Table 2-4 may be increased linearly. These values were calculated using a life table analysis that assumes the period of risk continues for the duration of the worker's lifetime. Somewhat smaller risks of serious genetic effects (if gonadal tissue is exposed) and of nonfatal cancer would also be incurred. An expanded discussion of health effects from radiation dose is provided in Appendix B.

Some workers performing emergency services will have little or no health physics training, so dose minimization through use of protective equipment cannot always be assumed. However, the use of respiratory protective equipment can reduce dose from inhalation, and clothing can reduce beta dose. Stable iodine is also recommended for blocking thyroid

Table 2-3 Health Effects Associated with Whole-Body Absorbed Doses Received Within a Few Hours[a] (see Appendix B)

Whole Body Absorbed dose (rad)	Early Fatalities[b] (percent)	Whole Body Absorbed dose (rad)	Prodromal Effects[c] (percent affected)
140	5	50	2
200	15	100	15
300	50	150	50
400	85	200	85
460	95	250	98

[a]Risks will be lower for protracted exposure periods.

[b]Supportive medical treatment may increase the dose at which these frequencies occur by approximately 50 percent.

[c]Forewarning symptoms of more serious health effects associated with large doses of radiation.

Table 2-4 Approximate Cancer Risk to Average Individuals from 25 Rem Effective Dose Equivalent Delivered Promptly (see Appendix C)

Age at exposure (years)	Appropriate risk of premature death (deaths per 1,000 persons exposed)	Average years of life lost if premature death occurs (years)
20 to 30	9.1	24
30 to 40	7.2	19
40 to 50	5.3	15
50 to 60	3.5	11

uptake of radioiodine in personnel involved in emergency actions where atmospheric releases include radioiodine. The decision to issue stable iodine should include consideration of established State medical procedures, and planning is required to ensure its availability and proper use.

References

DO-90 U.S. Department of Energy. Effectiveness of Sheltering in Buildings and Vehicles for Plutonium, DOE/EH-0159, U.S. Department of Energy, Washington (1990).

EP-87 U.S. Environmental Protection Agency. Radiation Protection Guidance to Federal Agencies for Occupational Exposure. Federal Register, 52, 2822; January 27, 1987.

NR-80 U.S. Nuclear Regulatory Commission. Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants. NUREG-0654, U.S. Nuclear Regulatory Commission, Washington, (1980).

CHAPTER 3

Protective Action Guides for the Intermediate Phase (Food and Water)

a) Accidental Radioactive Contamination of Human Food and Animal Feeds; Recommendations for State and Local Agencies*

b) Drinking Water**

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* These recommendations were published by FDA in 1982.

**Protective action recommendations for drinking water are under development by EPA.

DEPARTMENT OF HEALTH AND HUMAN SERVICES

Food and Drug Administration

[Docket No. 76N-0050]

Accidental Radioactive Contamination of Human Food and Animal Feeds; Recommendations for State and Local Agencies

AGENCY: Food and Drug Administration.

ACTION: Notice.

SUMMARY: The Food and Drug Administration (FDA) is publishing this notice to provide to State and local agencies responsible for emergency response planning for radiological incidents recommendations for taking protective actions in the event that an incident causes the contamination of human food or animal feeds. These recommendations can be used to determine whether levels of radiation encountered in food after a radiological incident warrant protective action and to suggest appropriate actions that may be taken if action is warranted. FDA has a responsibility to issue guidance on

appropriate planning actions necessary for evaluating and preventing contamination of human food and animal feeds and on the control and use of these products should they become contaminated.

FOR FURTHER INFORMATION CONTACT: Gail D. Schmidt, Bureau of Radiological Health (HFX-1), Food and Drug Administration, 5600 Fishers Lane, Rockville, MD 20857, 301-443-2850.

SUPPLEMENTARY INFORMATION:

Background

This guidance on accidental radioactive contamination of food from fixed nuclear facilities, transportation accidents, and fallout is part of a Federal interagency effort coordinated by the Federal Emergency Management Agency (FEMA). FEMA issued a final regulation in the Federal Register of March 11, 1982 (47 FR 10758), which reflected governmental reorganizations and reassigned agency responsibilities for radiological incident emergency response planning. A responsibility assigned to the Department of Health and Human Services (HHS) (and in turn delegated to FDA) is the responsibility to develop and specify to State and local governments protective actions and associated guidance for human food and animal feed.

In the Federal Register of December 15, 1978 (43 FR 58790), FDA published proposed recommendations for State and local agencies regarding accidental radioactive contamination of human food and animal feeds. Interested persons were given until February 13, 1979 to comment on the proposal. Twenty-one comments were received from State agencies, Federal agencies, nuclear utilities, and others. Two of the comments from environmentally concerned organizations were received after the March 28, 1979 accident at Three Mile Island, which increased public awareness of protective action guidance. Although these comments were received after the close of the comment period, they were considered by the agency in developing these final recommendations.

The Office of Radiation Programs, Environmental Protection Agency (EPA), submitted a detailed and exhaustive critique of the proposed recommendations. EPA addressed the dosimetry data, the agricultural models used in calculating the derived response levels, and the philosophical basis for establishing the numerical value of the protective action guides. FDA advises that, to be responsive to the EPA comments, FDA staff met with staff of the Office of Radiation Programs, EPA, during the development of these final recommendations. Although EPA's formal comments are responded to in this notice, EPA staff reviewed a draft of the final recommendations, and FDA has considered their additional informal comments. These contacts were considered appropriate because EPA has indicated that it intends to use the recommendations as the basis for revising its guidance to Federal agencies on protective action guides for radioactivity in food.

Protective Action Guidance

Although not raised in the comments received, FDA has reconsidered its proposal to codify these recommendations in 21 CFR Part 1090. Because these recommendations are voluntary guidance to State and local agencies (not regulations), FDA has decided not to codify the recommendations; rather, it is issuing them in this notice. Elsewhere in this issue of the Federal Register, FDA is withdrawing the December 15, 1978 proposal.

The recommendations contain basic criteria, defined as protective action guides (PAG's), for establishing the level of radioactive contamination of human food or animal feeds at which action should be taken to protect the public health and assure the safety of food. The recommendations also contain specific guidance on what emergency protective actions should be taken to prevent further contamination of food or feeds or to restrict the use of food, as well as more general guidance on the development and implementation of emergency action. The PAG's have been developed on the basis of considerations of acceptable risk to identify that level of contamination at which action is necessary to protect the public health.

In preparing these recommendations, FDA has reviewed and utilized the Federal guidance on protective actions contained in Federal Radiation Council (FRC) Reports No. 5, July 1964 (Ref. 1) and No. 7, May 1965 (Ref. 2). The Federal guidance provides that each Federal agency, by virtue of its immediate knowledge or its operating problems, would use the applicable FRC guides as a basis for developing detailed standards to meet the particular needs of the agency. FDA's recommendations incorporate the FRC concepts and the FRC guidance that protective actions, in the event of a contaminating accident, should be based on estimates of the projected radiation dose that would be received in the absence of taking protective actions. Similarly, protective actions should be implemented for a sufficient time to avoid most of the projected radiation dose. Thus, the PAG's define the numerical value of projected radiation doses for which protective actions are recommended.

FDA has reviewed the recent report of the National Academy of Sciences/National Research Council (Ref. 3) on radiation risks and biological effects data that became available after publication of the FRC guidance and has reviewed the impact of taking action in the pasture/cow/milk/person pathway in light of the current concerns in radiation protection. Based on these considerations and the comments received on the proposed recommendations, FDA has concluded that protective actions of low impact should be undertaken at projected radiation doses lower than those recommended by FRC (Refs. 1 and 2). Accordingly, FDA is recommending low-impact protective actions (termed the Preventive PAG) at projected radiation doses of 0.5 rem whole body and 1.5 rem thyroid. FDA intends that such protective actions be implemented to prevent the appearance of radioactivity in food at levels that would require its condemnation. Preventive PAG's include the transfer of dairy cows from fresh forage (pasture) to uncontaminated stored feed and the diversion of whole milk potentially contaminated with short-lived radionuclides to products with a long shelf life to allow radioactive decay of the radioactive material.

In those situations where the only protective actions that are feasible present high dietary and social costs or impacts (termed the Emergency PAG) action is recommended at projected radiation doses of 5 rem whole body and 15 rem thyroid. At the Emergency PAG level responsible officials should isolate food to prevent its introduction into commerce and determine whether condemnation or other disposition is appropriate. Action at the Emergency PAG level is most likely for the population that is near to the source of radioactive contamination and that consumes home-grown produce and milk.

The PAG's represent FDA's judgment as to that level of food contamination resulting from radiation incidents at which action should be taken to protect the public health. This is based on the agency's recognition that safety involves the degree to which risks are judged acceptable. The risk from natural disasters (approximately a one in a million annual individual risk of death) and the risk from variations in natural background radiation have provided

perspective in selecting the PAG values. This issue is further discussed in the responses to specific comments later in this notice, especially in paragraph 9. A more detailed treatment of the rationale, risk factors, dosimetric and agricultural models, and methods of calculation is contained in the "Background for Protective Action Recommendations; Accidental Radioactive Contamination of Food and Animal Feeds" (Ref. 22).

Organ PAG Values

Current scientific evidence, as reflected by BEIR–I (Ref. 18), UNSCEAR–1977 (Ref. 8), and BEIR–III (Ref. 3), indicates that the relative importance of risk due to specific organ exposure is quite different from the earlier assumptions. The International Commission on Radiological Protection (ICRP) clearly recognized this in its 1977 recommendations (ICRP–26 (Ref. 6)), which changed the methodology for treating external and internal radiation doses and the relative importance of specific organ doses. ICRP–26 assigned weighting factors to specific organs based on considerations of the incidence and severity (mortality) of radiation cancer induction. For the radionuclides of concern for food PAG's, ICRP–26 assigned weighting factors of 0.03 for the thyroid and 0.12 for red bone marrow. Thus, the organ doses equal in risk to 1 rem whole body radiation dose are 33 rem to the thyroid and 8 rem to Red bone marrow. (The additional ICRP–26, nonstochastic limit, however, restricts the thyroid dose to 50 rem or 10 times the whole body occupational limit of 5 rem.)

In the **Federal Register** of January 23, 1981 (46 FR 7836), EPA proposed to revise the Federal Radiation Protection Guidance for Occupational Exposures using the ICRP approach for internal organ radiation doses, modified to reflect specific EPA concerns. The EPA proposal has been subject to considerable controversy. Also, the National Council on Radiation Protection and Measurements (NCRP) curently is evaluating the need to revise its recommendations. FDA does not, however, expect the protection model for internal organ radiation doses to be resolved rapidly in the United States and has based the relative PAG dose assignments in these recommendations on current U.S. standards and the 1971 recommendations in NCRP–39 (Ref. 19). Thus, the red bone marrow is assigned the same PAG dose as the whole body (0.5 rem Preventive PAG), and the thyroid PAG is greater by a factor of three (1.5 rem Preventive PAG). This results in PAG assignments for the thyroid and red bone marrow that are lower by factors of 3.3 and 8, respectively, than values based on ICRP–26 (Ref. 6). FDA advises that it will make appropriate changes in recommendations for internal organ doses when a consensus in the United States emerges.

Analysis of Comments

The following is a summary of the comments received on the December 15, 1978 proposal and the agency's response to them:

1. Several comments requested clarification of the applicability and compatibility of FDA's recommendations with other Federal actions, specifically the PAG guidance of EPA (Ref. 7), the FRC Reports No. 5 (Ref. 1) and No. 7 (Ref. 2), and the Nuclear Regulatory Commission (NRC) definition of "Extraordinary Nuclear Occurrence" in 10 CFR Part 140. A comment recommended that the term, "Protective Action Guide (PAG)", not be used because that term traditionally has been associated with the FRC, and the general public would confuse FDA's recommendations with Federal guidance.

The FRC Report No. 5 specifically recommended that the term, "protective action guide," be adopted for Federal use. The report defines the term as the "projected absorbed dose to the individuals in the general population which warrants protective action following a contaminating event," a concept that is addressed by FDA's recommendations. To use the concept with a different description would, in FDA's opinion, be unnecessarily confusing to State and local agencies as well as Federal agencies.

These recommendations are being issued to fulfill the HHS responsibilities under FEMA's March 11, 1982 regulation. FDA fully considered FRC Reports No. 5 and No. 7 and the basic concepts and philosophy of the FRC guidance form the basis for these recommendations. The specific PAG values are derived response levels included in these recommendations are based on current agricultural pathway and radiation dose models and current estimates of risk. The FRC guidance provided that protective actions may be justified at lower (or higher) projected radiation doses depending on the total impact of the protective action. Thus, FDA's recommendation that protective actions be implemented at projected radiation doses lower than those recommended by FRC doses is consistent with the FRC guidance. The FRC guidance is applicable to Federal agencies in their radiation protection activities. FDA's recommendations are for use by State and local agencies in response planning and implementation of protective actions in the event of a contaminating incident. Further, FDA's recommendations would also be used by FDA in implementing its authority for food in interstate commerce under the Federal Food, Drug, and Cosmetic Act.

FDA's recommendations are being forwarded to EPA as the basis for revising Federal guidance on food accidentally contaminated by radionuclides. EPA has advised FDA that it intends to forward the FDA recommendations to the President under its authority to "advise the President with respect to radiation matters directly or indirectly affecting health, including guidance for all Federal agencies in the formulation of radiation standards * * *". (This authority was transferred to EPA in 1970 when FRC was abolished.)

The recommendations established in this document apply only to human food and animal feeds accidentally contaminated by radionuclides. They should not be applied to any other source of radiation exposure. EPA already has issued protective action guidance for the short-term accidental exposure to airborne releases of radioactive materials and intends also to forward the EPA guides to the President as Federal guidance. EPA also is considering the development of guidance for acidentally contaminated water and for long-term exposures due to contaminated land, property, and materials. Guidance for each of these exposure pathways is mutually exclusive. Different guidance for each exposure pathway is appropriate because different criteria of risk, cost, and benefit are involved. Also, each exposure pathway may involve different sets of protective or restorative actions and would relate to different periods of time when such actions would be taken.

2. Several comments expressed concern about radiation exposure from multiple radionuclides and from multiple pathways, e.g., via inhalation, ingestion, and external radiation from the cloud (plume exposure) and questioned why particular pathways or radionuclides and the does received before assessment were not addressed in the recommendations. Several comments recommended that the PAG's include specific guidance for tap water (and potable water). Other comments noted that particular biological forms of specific radionuclides (i.e., cyanocobalamin Co 60), would lead to significantly different derived response levels.

FDA advises that the PAG's and the protective action concepts of FRC apply to actions taken to avoid or prevent projected radiation dose (or future dose). Thus, by definition, the PAG's for food do not consider the radiation doses already incurred from the plume pathway or from other sources. The population potentially exposed by ingestion of contaminated food can be divided into that population near the source of contamination and a generally much larger population at distances where the doses from the cloud are not significant. The NRC regulations provide that State and local planning regarding plume exposure should extend for 10 miles and the ingestion pathway should extend for 50 miles (see 45 FR 55402; August 19, 1980). The total population exposed by ingestion, however, is a function of the animal feed and human food production of any given area and is not limited by distance from the source of contamination. Exposure from multiple pathways would not be a concern for the more distant population group. Further, individuals in this larger population would most likely receive doses smaller than that projected for continuous intake because the contaminated food present in the retail distribution system would be replaced by uncontaminated food.

FRC Report No. 5 states that, for repetitive occurrences, the total projected radiation dose and the total impact of protective actions should be considered. Similar considerations on a case-by-case basis would then appear to be appropriate in the case of multiple exposures from the plume and the ingestion pathway. Accordingly, the final recommendations are modified to note that, specifically in the case of the population near the site that consumes locally grown produce, limitations of the total dose should be considered (see paragraph (a)(2)). The agency concludes, however, that a single unified PAG covering multiple pathways, e.g., external radiation, inhalation, and ingestion is not practical because different actions and impacts are involved. Further, FDA's responsibility in radiological incident emergency response planning extends only to human food and animal feeds.

The agency's primary charge is to set recommended PAG dose commitment limits for the food pathway. Thus, deriving response levels for only the radionuclides most likely to enter the food chain and deliver the highest dose to the population permits FDA to establish recommendations that are practical for use in an emergency. In discussing with EPA the list of definitive models, FDA and EPA staffs agreed that further pathway studies would be useful. Elsewhere in this notice, FDA references models for other radionuclides, providing a resource for those requiring more details.

The chemical form of radionuclides in the environment may be important when considering the deriavation of an appropriate "response level" in specific situations, but would not change the PAG's, which are in terms of projected dose commitments. Cyanocobalamin Co 60 has not been identified as a likely constituent of health importance to be released from a nuclear reactor accident and, therefore, the agency rejects the recommendation that it provide derived response levels for this radionuclide. However, after reviewing current agricultural and dose models, the agency concludes that cesium-134 would likely be released and has added it to the tables in paragraph (d) of the recommendations identifying radionuclide concentrations equivalent to the PAG response levels.

FDA rejects the comment recommending that the PAG's include guidance for water. A memorandum of understanding between EPA and FDA provides that FDA will have primary responsibility over direct and indirect additives and other substances in drinking water (see 44 FR 42775; July 20, 1979). Thus, FDA defers to EPA for developing guides specifically for drinking water.

3. Three comments requested clarification of the proposed recommendations, including the time over which the guides apply, the time of ingestion required to reach the PAG, and the time that protective actions should be implemented.

FDA advises that the recommendations are intended to provide guidance for actions to be implemented in an emergency, and the duration of protective action should not exceed 1 or 2 months. The agency believes that the actions identified in paragraphs (a) and (h) of the recommendations should be continued for a sufficient time to avoid most of the emergency radiation dose and to assure that the remaining dose is less than the Preventive PAG. This period of time can be estimated by considering the effective half-life of the radioactive material taking into account both radioactive decay and weathering. Each case must be examined separately considering the actual levels of contamination and the effective half-life of the radioactive material present. For the pasture/cow/milk pathway, the effective half-lives are 5 days for iodine-131 and 14 days for cesium or strontium. Assuming that initial contamination by these radionuclides was at the Preventive PAG level, radioactive decay and weathering would reduce the levels so that protective actions could be ceased after 1 or 2 months.

The model used to compute the derived response levels specified in paragraph (d) of the recommendations assumes a continous or infinite ingestion period, i.e., intake that is limited only by radioactive decay and weathering. This is the approach recommended in estimating the projected radiation dose (in the absence of protective actions.). Further revisions have been made in the recommendations to clarify these aspects.

4. A comment stated that action should be initiated by notification received from the facility itself. Another comment noted the importance of timely announcements to the public of the necessity for protective actions.

These recommendations on protective action guides for food and feed are not intended to cover other aspects of emergency planning for radiological incidents. The general responsibilities of NRC licensees in radiation emergencies have been further defined in a rule issued by NRC (45 FR 55402; August 19, 1980). FDA recognizes, however, that notification and public announcements are vital to effective protective actions and, in paragraph (e)(5) of the recommendations, urges that State and local emergency plans should provide for such notice.

5. A comment offered clarification of proposed § 1000.400(g) regarding verification of sample measurements, while another comment suggested that Preventive PAG's should be based on projected levels and that Emergency PAG.s require verification.

The FRC concepts and philosophy, which FDA fully endorses, use estimates of projected radiation dose as the criteria for taking protective action. FDA believes that projected radiation dose estimates should be based on verified measurements of radioactivity in the food pathway. Such verification might include the analysis of replicate samples, laboratory measurements, sample analysis by other agencies, samples of various environmental media, and descriptive data of the radioactive release and has so provided in paragraph (g) of the recommendations.

6. A comment suggested that some States do not have the resources to evaluate projected radiation doses. The comment asked what regulatory agency would have control over interstate

shipment of contaminated foods from States without sufficient resources and what would be the applicable PAG.

FEMA, as the lead agency for the Federal effort, is providing to States guidance and assistance on emergency response planning including evaluation of projected doses. Also, NRC requires nuclear power plant licensees to have the capability to assess the off-site consequences of radioactivity releases and to provide notification to State and local agencies (45 FR 55402; August 19, 1980). FDA has authority under the Federal Food, Drug, and Cosmetic Act to remove radioactively contaminated food from the channels of interstate commerce. In this circumstance, FDA would use these PAG recommendations as the basis for implementing regulatory action.

Risk Estimates

7. Many comments questioned the risk estimates on which FDA based the proposed PAG's. The comments especially suggested that risk estimates from WASH-1400 (Ref. 4) were of questionable validity. Other comments argued that the proposed recommendations used an analysis of only lethal effects; that they used an absolute risk model; and that genetic effects were not adequately considered. The risk estimates themselves were alleged to be erroneous because recent studies show that doubling doses are lower than are those suggested by WASH=1400. The tinea capitis study by Ron and Modan, which indicates an increased probability of thyroid cancer at an estimated radiation dose of 9 rem to the thyroid (Ref. 5), was cited as evidence that the PAG limits for the thyroid were too high. The comments requested further identification and support for using the critical population selected.

Most of these issues were addressed in the preamble to the FDA proposal. The final recommendations issued in this notice employ the most recent risk estimates (somatic and genetic) of the National Academy of Sciences Committee on Biological Effects of Ionizing Radiation (Ref. 3).

The thyroid PAG limits are based on the relative radiation protection guide for thyroid compared to whole body contained in NRC's current regulations (10 CFR Part 20). The derived response levels for thyroid are based on risk factors for external x-ray irradiation. Therefore, the criticism of the PAG limits for the thyroid is not applicable, no "credit" having been taken for an apparent lower radiation risk due to iodine-131 irradiation of the thyroid gland. Further, as discussed above under "ORGAN PAG VALUES", the use of BEIR-III risk estimates or the ICRP-26 recommendations would result in an increase of the thyroid PAG relative to the whole body PAG. For these reasons, FDA believes the PAG limits for projected dose commitment to the thyroid are conservative when considered in light of current knowledge of radiation to produce equal health risks from whole body and specific organ doses.

Although it may be desirable to consider total health effects, not just lethal effects, there is a lack of data for total health effects to use in such comparisons. In the case of the variability of natural background, as an estimate of acceptable risk, consideration of lethal effects or total health effects is not involved because the comparison is the total dose over a lifetime.

Rational

8. Several comments questioned the rational FDA used in setting the specific PAG values included in the December 1978 proposal. A comment from EPA stated that the guidance levels should be justified on the grounds that it is not practical or reasonable to take protective actions at lower risk levels. Further, EPA argued that the protective action concept for emergency planning and response should incorporate the principle of keeping radiation exposures as low as reasonably achievable (ALARA). EPA noted that the principle of acceptable risk involves a perception of risk that may vary from person to person and that the implication that an acceptable genetic risk has been established should be avoided.

FDA accepts and endorses the ALARA concept, but the extent to which a concept, which is used in occupational settings, should be applied to emergency protective actions is not clear. To use the ALARA concept as the basis for specific PAG values and also require ALARA during the implementation of emergency protective actions appears to be redundant and may not be practical under emergency conditions.

FDA advises that these guides do not constitute acceptable occupational radiation dose limits nor do they constitute acceptable limits for other applications (e.g., acceptable genetic risk). The guides are not intended to be used to limit the radiation dose that people may receive but instead are to be compared to the calculated projected dose, i.e., the future dose that the people would receive if no protective action were taken in a radiation emergency. In this respect, the PAG's represent trigger levels calling for the initiation of recommended protective actions. Once the protective action is initiated, it should be executed so as to prevent as much of the calculated projected dose from being received as is reasonably achievable. This does not mean, however, that all doses above guidance levels can be prevented.

Further, the guides are not intended to prohibit taking actions at projected exposures lower than the PAG values. They have been derived for general cases and are just what their name implies, guides. As provided in FRC Reports No. 5 and No. 7 and as discussed in paragraph 1 of this notice, in the absence of significant constraints, responsible authority may find it appropriate to implement low-impact protective actions at projected radiation doses less than those specified in the guides. Similarly, high impact actions may be justified at higher projected doses. These judgments must be made according to the facts of each situation. Paragraphs (a) (2) and (3) have been added to the final recommendations to incorporate this concept.

9. Several comments questioned the adequacy of the level of risk judged acceptable in deriving the proposed PAG values. A comment stated that the estimated one in a million annual individual risk of death from natural disasters is extremely conservative. EPA suggested that comparative risk is appropriate for perspective but not for establishing the limits. EPA further suggested that the population-weighted average of the variability in natural background dose or the variation in dose due to the natural radioactivity in food should be the basis for judging acceptable risk.

FDA concludes that the differences between EPA's suggested approach and that employed by FDA largely involve the semantics of the rationale descriptions. As discussed in the preamble to the proposal, FDA believes that safety (or a safe level of risk) needs to be defined as the degree to which the risks are judged acceptable, because it is not possible to achieve zero risk from human endeavors. Further, ICRP (Ref. 6) recommends that, for a given application involving radiation, the net benefit to society should be positive, considering the total costs and impacts and the total benefit (this is termed, "justification"). FDA believes that, to establish a PAG, the primary concern is to provide adequate protection (or safe level of risk) for members of the public. To decide on safety or levels of acceptable risk to the public from a contaminating event, FDA introduced the estimates of acceptable risk from

natural disasters and background radiation. These values provided background or perspective for FDA's judgment that the proposed PAG's represent that level of food or feed radiation contamination at which protective actions should be taken to protect the public health; judgment which, consistent with FRC Report No. 5, also involves consideration of the impacts of the action and the possibility of future events. The recommendations are based on the assumption that the occurrences of environmental contamination requiring protective actions in a particular area is an unlikely event, that most individuals will never be so exposed, and that any individual is not likely to be exposed to projected doses at the PAG level more than once in his or her lifetime.

FDA continues to believe that the average risks from natural disasters and variation of background radiation provide appropriate bases for judging the acceptability of risk represented by the Preventive PAG. These recommendations incorporate the philosophy that action should be taken at the Preventive PAG level of contamination to avoid a potential public health problem. Should this action not be wholly successful, the Emergency PAG provides guidance for taking action where contaminated food is encountered. FDA expects that action at the Emergency PAG level of contamination would most likely involve food produced for consumption by the population near the source of contamination. As discussed in paragraph 2, this is also the population which might receive radiation doses from multiple pathways. Thus, the Emergency PAG might be considered to be an upper bound for limiting the total radiation dose to individuals. FDA emphasizes, however, that the Emergency PAG is not a boundary between safe levels and hazardous or injury levels of radiation. Individuals may receive an occupational dose of 5 rem each year over their working lifetime with the expectation of minimal increased risks to the individual. Persons in high elevation areas such as Colorado receive about 0.04 rem per year (or 2.8 rem in a lifetime) above the average background radiation dose for the United States population as a whole. The Emergency PAG is also consistent with the upper range of PAG's proposed by EPA for the cloud (plume) pathway (Ref. 7).

FDA agrees that a population-weighted variable is as applicable to the evaluation of comparative risks as is a geographic variable. Arguments can be made for using either variable. Because persons rather than geographic areas are the important parameter in the evaluation of risk associated with these guides, FDA has used population-weighting in estimating the variability of the annual external dose from natural radiation. A recent EPA study (Ref. 20) indicates that the average population dose from external background radiation dose is 53 millirem (mrem) per year, and the variability in lifetime dose taken as two standard deviations is about 2,000 mrem. The proposal, which indicated that the variation in external background was about 600 mrem, utilized a geographic weighting of State averages.

Radioactivity in food contributes about 20 mrem per year to average population doses and about 17 mrem per year of this dose results from potassium-40 (Ref. 8). Measurements of potassium-40 (and stable potassium) indicate that variability (two standard deviations) of the potassium-40 dose is about 28 percent or a lifetime dose of 350 mrem. It should be noted that body levels of potassium are regulated by metabolic processes and not dietary selection or residence. The variation of the internal dose is about one-fifth of the variation from external background radiation. FDA has retained the proposed preventive PAG of 500 mrem whole body even though the newer data indicate a greater variation in external background radiation.

FDA did not consider perceived risks in deriving the proposed PAG values because perceived risk presents numerous problems in its appropriateness and application. If the factor of perception is added to the equation, scientific analysis is impossible.

10. Two comments questioned the assumptions that the Emergency PAG might apply to 15 million people and that the Preventive PAG might apply to the entire United States. One comment noted that 15 million persons are more than that population currently within 25 miles of any United States reactor sites; thus, using this figure results in guides more restrictive than necessary. The other comment noted that, by reducing the population involved, and unacceptably high value could result.

The ratio of total United States population to the maximum number of people in the vicinity of an operating reactor could be erroneously interpreted so that progressively smaller populations would be subject to progressively larger individual risks. This is not the intent of the recommendations. Hence, the risk from natural disasters, the variation in the population-weighted natural background radiation dose to the total population, and the variation in dose due to ingestion of food, have been used to provide the basis for the Preventive PAG. The basis for the Emergency PAG involves considerations of (1) The ratio between average and maximum individual radiation doses (taken as 1 to 10), (2) the cost of low and high impact protective actions, (3) the relative risks from natural disasters, (4) health impact, (5) the upper range of the PAG's proposed by EPA (5 rem projected radiation dose to the whole body and 25 rem projected dose to the thyroid), and (6) radiation doses from multiple pathways.

11. A comment, citing experience with other contaminants, suggested that further consideration should be given to the problem of marketability of foods containing low levels of radioactivity.

Marketability is not a concern for PAG development. However, the publication of the PAG's should enhance marketability of foods because it will enhance public confidence in food safety. Also, FEMA has been specifically directed to undertake a public information program related to radiation emergencies to allay public fears and perceptions.

12. A comment noted the difficulty in assessing the impacts of and the benefits to be gained from protective actions. Another comment suggested that there were lower impact actions which could be implemented to keep food off the market until radiation levels in the food approach normal background.

The recommendation that planning officials consider the impacts of protective actions in implementing action does not imply that a mathematical analysis is required. Rather, FDA intends that the local situation, resources, and impacts that are important in assuring effective protective actions be considered in selecting any actions to be implemented. As discussed in paragraph 8, if the local constraints permit a low impact action, this can be appropriate at lower projected doses. Because it is not possible in general guidance to consider fully all local constraints, the PAG's represent FDA's judgment as to when protective actions are appropriate.

Agricultural and Dose Models

13. Several comments noted errors either in approach or calculations regarding the proposed agricultural and dose models, while others specifically noted that there are newer and better

models for use in computation of the derived response levels.

FDA appreciates the careful review and the suggestions as to better data and models. The references suggested, as well as other current reports, have been carefully reviewed and appropriate ones are being used as the basis for computation of the derived response levels for the final PAG's. The specific models and data being used are as follows:

Agricultural Model—UCRL-51939, 1977 (Ref. 9).

Intake per unit deposition—Table B-1, UCRL-51939 (Ref. 9).

Peak milk activity—Equation 8, UCRL-51939 (Ref. 9).

Area grazed by cow—45 square meters/day. UCRL-51939 (Ref. 9).

Initial retention on forage—0.5 fraction, UCRL-51939 (Ref. 9).

Forage yield—0.25 kilogram/square meter (dry weight), UCRL-51939 (Ref. 9).

Milk consumption—0.7 liter/day infant, ICRP-23, 1974 (Ref. 10);—0.55 liter/day adult, USDA, 1965 (Ref. 11).

Dose conversion factors (rem per microcurie ingested).

	Infant	Adult	
Iodine-131	16	1.6	Wellman and Anger, 1971 (Ref. 12).
Cesium-134	0.118	0.068	Adult—ORNL/NUREG/TM-190, 1978 (Ref. 13). Infant—Extrapolated from adult based on relative body weight 70 kilograms (kg) and 7.7 kg and effective retention, 102 days and 19.5 days, adult and infant respectively.
Cesium-137	0.071	0.061	NCRP No. 52, 1977 (Ref. 14).
Strontium-89	0.194	0.012	Adult, ICRP-30, 1979 (Ref. 15).
Strontium-90	2.49	0.70	Infant, Papworth and Vennart, 1973 (Ref. 16).

The use of the newer agricultural model (Ref. 9) has resulted in a 20 percent increase in the iodine-131 derived response levels identified in paragraph (d)(1) and (d)(2) of the recommendations. Generally, similar magnitude changes are reflected in the derived response levels for the other radionuclides. Newer data on iodine-131 dose conversion factors (Ref. 17) would have further increased the derived response levels for that radionuclide by about 40 percent, but these data have not been used pending their acceptance by United States recommending authorities. In addition, the proposal contained a systematic error in that the pasture derived response levels were stated to be based on fresh weight but were in fact based on dry weight. Fresh weight values (⅛ of dry weight values) are identified in the final recommendations and are listed under "Forage Concentration".

Other Comments

14. A comment addressed the definition of the critical or sensitive population for the tables in proposed § 1090.400(d) and observed that there is a greater risk per rem to the younger age groups than to adults. Another comment requested further explanation of the relative ability to protect children and adults.

FDA agrees that, ideally, the critical segment of the population should be defined in terms of the greatest risk per unit intake. However, this would introduce greater complexity into the recommendations than is justified, because the risk estimates are uncertain. The final recommendations provide derived response levels for infants at the Preventive PAG and infants and adults for the Emergency PAG.

FDA has reexamined the available data and concludes that taking action at the Preventive PAG (based on the infant as the critical or sensitive population) will also provide protection of the fetus from the mother's ingestion of milk. The definition of newborn infant in the tables in paragraph (d) of the PAG's has been revised to reflect this conclusion.

15. EPA commented that its regulations governing drinking water (40 CFR Subchapter D) permit blending of water to meet maximum contaminant levels. EPA suggested that FDA's short-term recommendations should be compatible with the long-term EPA regulations.

As stated in paragraphs 1 and 2 of this notice, FDA's recommendations apply to human food and animal feed, whereas EPA is responsible for providing guidance on contaminated water. Also, as discussed in paragraph 3 of the proposal, there is a long-standing FDA policy that blending of food is unlawful under the Federal Food, Drug, and Cosmetic Act. Further, these guides are intended for protective actions under emergency situations and are not for continuous exposure applications. For these reasons, FDA concludes that the differences between its recommendations and EPA's regulations are appropriate.

16. Two comments were received on the adequacy or availability of resources for sampling and analysis of State, local, and Federal agencies and the adequacy of guidance on sampling procedures.

These recommendations are not designed to provide a compendium of sampling techniques, methods, or resources. The Department of Energy through its Interagency Radiological Assistance Plan (IRAP) coordinates the provision of Federal assistance and an Offsite Instrumentation Task Force of the Federal Radiological Preparedness Coordinating Committee administered by FEMA is developing specific guidance on instrumentation and methods for sampling food (Ref. 21).

Cost Analysis

17. Several comments argued that FDA's cost/benefit analysis used to establish the PAG levels was inadequate. Comments stated that it is not appropriate to assign a unique fixed dollar value to the adverse health effects associated with one person-rem of dose.

FDA advises that its cost/benefit analysis was not conducted to establish the PAG levels. FDA considers such use inappropriate in part because of the inability to assess definitively the total societal impacts (positive and negative) of such actions. Rather, the cost/benefit analysis was used to determine whether protective actions at the recommended PAG's would provide a net societal benefit. To make such an assessment, it is necessary to place a dollar value on a person-rem of dose.

18. Several comments also questioned the appropriateness of the assumption in the cost/benefit analysis of 23 days of protective action, the need to address radionuclides other than iodine-131, and the need to consider the impact of other protective actions.

The cost assessments have been extensively revised to consider all the radionuclides for which derived response levels are provided in the recommendations and to incorporate updated cost data and risk estimates (Ref. 22). The cost/benefit analysis is limited to the condemnation of milk and the use of stored feed because accident analyses indicate that the milk pathway is the most likely to require protective action. Further, these two actions are the most likely protective actions that will be implemented.

FDA approached the cost/benefit analysis by calculating the concentration of radioactivity in milk at which the cost of taking action equals the risk avoided by the action taken on a daily milk intake basis. The assessment was done on a population basis and considered only the direct costs of the protective actions. The analysis indicates that, for restricting feed to stored feed, the cost-equals-benefit concentrations are about one-fiftieth to one-eightieth of the Preventive PAG level (derived peak milk concentration) for iodine-131, cesium-134, and cesium-137 and about one-third

of the level for strontium-89 and strontium-90. For condemnation of milk, based on value at the farm, the cost-equals-benefit concentrations are similar fractions of the Emergency PAG levels (derived peak milk concentration). If condemnation of milk is based on retail market value, the cost-equals-benefit concentrations are greater by a factor of two. Thus, it appears that protective actions at the Preventive or Emergency PAG levels will yield a net societal benefit. However, in the case of strontium-89 and strontium-90, protective action will yield a benefit only for concentrations greater than about one-third the derived peak values. In the case of iodine-131, cesium-134, and cesium-137, protective actions could be continued to avoid 95 percent of the projected radiation dose for initial peak concentrations at the PAG level.

References

The following information has been placed on display in the Dockets Management Branch (HFA-305), Food and Drug Administration, Rm. 4-62, 5600 Fishers Lane, Rockville, MD 20857, and may be seen between 9 a.m. and 4 p.m., Monday through Friday.

1. Federal Radiation Council, Memorandum for the President, "Radiation Protection Guidance for Federal Agencies," Federal Register, August 22, 1964 (29 FR 12056), and Report No. 5 (July 1964).

2. Federal Radiation Council, Memorandum for the President, "Radiation Protection Guidance for Federal Agencies," Federal Register," May 22, 1965 (30 FR 6953), and Report No. 7 (May 1965).

3. National Academy of Sciences/National Research Council, "The Effects on Population of Exposure to Low Levels of Ionizing Radiation," Report of the Advisory Committee on Biological Effects of Ionizing Radiation (BEIR-III) (1980).

4. United States Nuclear Regulatory Commission, Reactor Safety Study, WASH-1400, Appendix VI (October 1975).

5. Ron, E. and B. Modan, "Benign and Malignant Thyroid Neoplasms After Childhood Irradiation for Tinea Capitis," *Journal of the National Cancer Institute*, Vol. 65, No. 1 (July 1980).

6. International Commission on Radiological Protection (ICRP), Recommendations of the International Commission on Radiological Protection, ICRP Publication 26, Annals of the ICRP, Pergamon Press (1977).

7. Environmental Protection Agency, "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," EPA 520/1-75-001, revised June 1980.

8. United Nations Scientific Committee on the Effects of Atomic Radiation, 1977 Report, United Nations, New York (1977).

9. Ng, Y. C., C. S. Colsher, D. J. Quinn, and S. E. Thompson, "Transfer Coefficients for the Prediction of the Dose to Man Via the Forage-Cow-Milk Pathway from Radionuclides Released to the Biosphere," UCRL-51939, Lawrence Livermore Laboratory (July 15, 1977).

10. International Commission on Radiological Protection, Report of a Task Group of Committee 2 on Reference Man, Publication 23, p. 360, Pergamon Press, Oxford (1974).

11. U.S. Department of Agriculture, "Household Food Consumption Survey 1965-1966."

12. Wellman, H. N. and R. T. Anger, "Radioiodine Dosimetry and the Use of Radioiodines Other Than ^{131}I in Thyroid Diagnosis," *Seminars in Nuclear Medicine*, 3:356 (1971).

13. Killough, G. G., D. E. Dunning, S. R. Bernard, and J. C. Pleasant, "Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel-Cycle Facilities, Vol. 1," ORNL/NUREG/TM-190, Oak Ridge National Laboratory (June 1978).

14. National Council on Radiation Protection and Measurements, "Cesium-137 From the Environment to Man: Metabolism and Dose," NCRP Report No. 52, Washington (January 15, 1977).

15. International Commission on Radiological Protection, Limits for Intakes of Radionuclides by Workers, ICRP Publication 30, Part 1, Annals of the ICRP, Pergamon Press (1979).

16. Papworth, D. G., and J. Vennart, "Retention of ^{90}Sr in Human Bone at Different Ages and Resulting Radiation Doses," *Physics in Medicine and Biology*, 18:169-186 (1973).

17. Kereiakes, J. G., P. A. Feller, F. A. Ascoli, S. R. Thomas, M. J. Gelfand, and E. L. Saenger, "Pediatric Radiopharmaceutical Dosimetry" *in* "Radiopharmaceutical Dosimetry Symposium," April 26-29, 1976, HEW Publication (FDA) 76-8044 (June 1976).

18. National Academy of Sciences/National Research Council, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," Report of the Advisory Committee on Biological Effects of Ionizing Radiation (BEIR-I) (1972).

19. National Council on Radiation Protection and Measurements (NCRP), "Basic Radiation Protection Criteria," NCRP Report No. 39, Washington (1971).

20. Bogen, K. T., and A. S. Goldin, "Population Exposure to External Natural Radiation Background in the United States," ORP/SEPD-80-12, Environmental Protection Agency, Washington, DC (April 1981).

21. Federal Interagency Task Force on Offsite Emergency Instrumentation for Nuclear Accidents, "Guidance on Offsite Emergency Radiation Measurement Systems: Phase 2, Monitoring and Measurement of Radionuclides to Determine Dose Commitment in the Milk Pathway," developed by Exxon Nuclear Idaho Co. Inc., Idaho Falls, ID, Draft, July 1981 (to be published by FEMA).

22. Shleien, B., G. D. Schmidt, and R. P. Chiacchierini, "Background for Protective Action Recommendations; Accidental Radioactive Contamination of Food and Animal Feeds," September 1981, Department of Health and Human Services, Food and Drug Administration, Bureau of Radiological Health, Rockville, MD.

Pertinent background data and information on the recommendations are on file in the Dockets Management Branch, and copies are available from that office (address above).

Based upon review of the comments received on the proposal of December 15, 1978 (43 FR 58790), and FDA's further consideration of the need to provide guidance to State and local agencies for use in emergency response planning in the event that an incident results in the radioactive contamination of human food or animal feed, the agency offers the following recommendations regarding protective action planning for human food and animal feeds:

Accidental Radioactive Contamination of Human Food and Animal Feeds; Recommendations for State and Local Agencies

(a) *Applicability.* (1) These recommendations are for use by appropriate State or local agencies in response planning and the conduct of radiation protection activities involving the production, processing, distribution, and use of human food and animal feeds in the event of an incident resulting in the lease of radioactivity to the environment. The Food and Drug Administration (FDA) recommends that this guidance be used on a case-by-case basis to determine the need for taking appropriate protective action in the event of a diversity of contaminating events, such as nuclear facility accidents, transportation accidents, and fallout from nuclear devices.

(2) Protective actions are appropriate when the health benefits associated with the reduction in exposure to be achieved are sufficient to offset the undesirable features of the protective actions. The Protective Action Guides (PAG's) in paragraph (c) of these recommendations represent FDA's judgment as to the level of food contamination resulting from radiation incidents at which protective action should be taken to protect the public health. Further, as provided by Federal guidance issued by the Federal Radiation Council, if, in a particular situation, and effective action with low total impact is available, initiation of such action at a projected dose lower than the PAG may be justifiable. If only very high-impact action would be effective, initiation of such action at a projected dose higher than the PAG may be justifiable. (See 29 FR 12056; August 22, 1964.) A basic assumption in the development of protective action guidance is that a condition requiring protective action is unusual and should not be expected to occur frequently.

Circumstances that involve repetitive occurrence, a substantial probability of recurrence within a period of 1 or 2 years, or exposure from multiple sources (such as airborne cloud and food pathway) 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 future dose from one or more of these events may need to be considered. In any event, the numerical values selected for the PAG's are not intended to authorize deliberate releases expected to result in absorbed doses of these magnitudes.

(3) A protective action is an action or measure taken to avoid most of the radiation dose that would occur from future ingestion of foods contaminated with radioactive materials. These recommendations are intended for implementation within hours or days from the time an emergency is recognized. The action recommended to be taken should be continued for a sufficient time to avoid most of the projected dose. Evaluation of when to cease a protective action should be made on a case-by-case basis considering the specific incident and the food supply contaminated. In the case of the pasture/cow/milk/person pathway, for which derived "response levels" are provided in paragraph (d) of these recommendations, it is expected that actions would not need to extend beyond 1 or 2 months due to the reduction of forage concentrations by weathering (14-day half-life assumed). In the case of fresh produce directly contaminated by deposition from the cloud, actions would be necessary at the time of harvest. This guidance is not intended to apply to the problems of long-term food pathway contamination where adequate time after the incident is available to evaluate the public health consequences of food contamination using current recommendations and the guidance in Federal Radiation Council (FRC) Report No. 5, July 1964 and Report No. 7, May 1965.

(b) *Definitions.* (1) "Dose" is a general term denoting the quantity of radiation or energy absorbed. For special purposes it must be appropriately qualified. In these recommendations it refers specifically to the term "dose equivalent."

(2) "Dose commitment" means the radiation dose equivalent received by an exposed individual to the organ cited over a lifetime from a single event.

(3) "Dose equivalent" is a quantity that expresses all radiation on a common scale for calculating the effective absorbed dose. It is defined as the product of the absorbed dose in rads and certain modifying factors. The unit of dose equivalent is the rem.

(4) "Projected dose commitment" means the dose commitment that would be received in the future by individuals in the population group from the contaminating event if no protective action were taken.

(5) "Protective action" means an action taken to avoid most of the exposure to radiation that would occur from future ingestion of foods contaminated with radioactive materials.

(6) "Protective action guide (PAG)" means the projected dose commitment values to individuals in the general population that warrant protective action following a release of radioactive material. Protective action would be warranted if the expected individual dose reduction is not offset by negative social, economic, or health effects. The PAG does not include the dose that has unavoidably occurred before the assessment.

(7) "Preventive PAG" is the projected dose commitment value at which responsible officials should take protective actions having minimal ipact to prevent or reduce the radioactive contamination of human food or animal feeds.

(8) "Emergency PAG" is the projected dose commitment value at which responsible officials should isolate food containing radioactivity to prevent its introduction into commerce and at which the responsible officials should determine whether condemnation or another disposition is appropriate. At the Emergency PAG, higher impact actions are justified because of the projected health hazards.

(9) "Rad" means the unit of absorbed dose equal to 0.01 Joule per kilogram in any medium.

(10) "Rem" is a special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor, and any other necessary modifying factors.

(11) "Response level" means the activity of a specific radionuclide (i) initially deposited on pasture; or (ii) per unit weight or volume of food or animal feed; or (iii) in the total dietary intake which corresponds to a particular PAG.

(c) *Protective action guides (PAG's).* To permit flexibility of action for the reduction of radiation exposure to the public via the food pathway due to the occurrence of a contaminating event, the following Preventive and Emergency PAG's for an exposed individual in the population are adopted:

(1) *Preventive PAG* which is (i) 1.5 rem projected dose commitment to the thyroid, or (ii) 0.5 rem projected dose commitment to the whole body, bone marrow, or any other organ.

(2) *Emergency PAG* which is (i) 15 rem projected dose commitment to the thyroid, or (ii) 5 rem projected dose commitment to the whole body, bone marrow, or any other organ.

(d) *Response levels equivalent to PAG.* Although the basic PAG recommendations are given in terms of projected dose equivalent, it is often more convenient to utilize specific radionuclide concentrations upon which to initiate protective action. Derived response levels equivalent to the PAG's for radionuclides of interest are:

(1) *Response level for Preventive PAG.* Infant [1] as critical segment of population.

[1] Newborn infant includes fetus (pregnant women) as critical segment of population for iodine-131. For other radionuclides, "infant" refers to child less than 1 year of age.

Response levels for preventive PAG	^{131}I [2]	^{134}Cs [4]	^{137}Cs [4]	^{90}Sr	^{89}Sr
Initial Activity Area Deposition (microcuries/square meter)	0.13	2	3	0.5	8
Forage Concentration [3] (microcuries/kilogram)	0.05	0.8	1.3	0.18	3
Peak Milk Activity (microcuries/liter)	0.015	0.15	0.24	0.009	0.14
Total intake (microcuries)	0.09	4	7	0.2	2.6

[2] From fallout, iodine-131 is the only radioiodine of significance with respect to milk contamination beyond the first day. In case of a reactor accident, the cumulative intake of iodine-133 via milk is about 2 percent of iodine-131 assuming equivalent deposition.

[3] Fresh weight.

[4] Intake of cesium via the meat/person pathway for adults may exceed that of the milk pathway; therefore, such levels in milk should cause surveillance and protective actions for meat as appropriate. If both cesium-134 and cesium-137 are equally present as might be expected for reactor accidents, the response levels should be reduced by a factor of two.

(2) *Response level for Emergency PAG.* The response levels equivalent to the Emergency PAG are presented for both infants and adults to permit use of either level and thus assure a flexible approach to taking action in cases where exposure of the most critical portion of the population (infants and pregnant women) can be prevented:

Response levels for emergency PAG	131_I[3]		134_{Cs}[5]		137_{Cs}[5]		90_{Sr}		89_{Sr}	
	Infant[1]	Adult	Infant[2]	Adult	Infant[2]	Adult	Infant[2]	Adult	Infant[2]	Adult
Initial Activity Area Deposition (microcuries/square meter)	1.3	18	20	40	30	50	5	20	80	1600
Forage Concentration [4] (microcuries/kilogram)	0.5	7	8	17	13	19	1.8	8	30	700
Peak Milk Activity (microcuries/liter)	0.15	2	1.5	3	2.4	4	0.09	0.4	1.4	30
Total intake (microcuries)	0.9	10	40	70	70	80	2	7	26	400

[1] Newborn infant includes fetus (pregnant women) as critical segment of population for iodine-131.
[2] "Infant" refers to child less than 1 year of age.
[3] From fallout, iodine-131 is the only radioiodine of significance with respect to milk contamination beyond the first day. In case of a reactor accident the cumulative intake of iodine-133 via milk is about 2 percent of iodine-131 assuming equivalent deposition.
[4] Fresh weight.
[5] Intake of cesium via the meat/person pathway for adults may exceed that of the milk pathway; therefore, such levels in milk should cause surveillance and protective actions for meat as appropriate. If both cesium-134 and cesium-137 are equally present, as might be expected for reactor accidents, the response levels should be reduced by a factor of 2.

(e) *Implementation.* When using the PAG's and associated response levels for response planning or protective actions, the following conditions should be followed:

(1) *Specific food items.* To obtain the response level (microcurie/kilogram) equivalent to the PAG for other specific foods, it is necessary to weigh the contribution of the individual food to the total dietary intake; thus,

$$\text{Response Level} = \frac{\text{Total intake (microcuries)}}{\text{Consumption (kilograms)}}$$

Where: Total intake (microcuries) for the appropriate PAG and radionuclide is given in paragraph (d) of these recommendations
and
Consumption is the product of the average daily consumption specified in paragraph (e)(1)(i) of these recommendations and the days of intake of the contaminated food as specified in paragraph (e)(1)(ii) of these recommendations.

(i) The daily consumption of specific foods in kilograms per day for the general population is given in the following table:

Food	Average consumption for the general population (kilogram/day)
Milk, cream, cheese, ice cream [1]	.570
Fats, oils	.055
Flour, cereal	.091
Bakery products	.150
Meat	.220
Poultry	.055
Fish and shellfish	.023
Eggs	.055
Sugar, sirups, honey, molasses, etc.	.073
Potatoes, sweet potatoes	.105
Vegetables, fresh (excluding potatoes)	.145
Vegetables, canned, frozen, dried	.077
Vegetables, juice (single strength)	.009
Fruit, fresh	.165
Fruit, canned, frozen, dried	.036
Fruit, juice (single strength)	.045
Other beverages (soft drinks, coffee, alcoholic)	.180
Soup and gravies (mostly condensed)	.036
Nuts and peanut butter	.009
Total	2.099

[1] Expressed as calcium equivalent; that is, the quantity of whole fluid milk to which dairy products are equivalent in calcium content.

(ii) Assessment of the effective days of intake should consider the specific food, the population involved, the food distribution system, and the radionuclide. Whether the food is distributed to the retail market or produced for home use will significantly affect the intake in most instances. Thus, while assessment of intake should be on a case-by-case basis, some general comments may be useful in specific circumstances.

(*a*) For short half-life radionuclides, radioactive decay will limit the ingestion of radioactive materials and the effective "days of intake". The effective "days of intake" in this case is 1.44 times the radiological half-life. For iodine–131 (half-life—8.05 days), the effective "days of intake" is, thus, 11 days.

(*b*) Where the food product is being harvested on a daily basis, it may be reasonable to assume reduction of contamination due to weathering. As an initial assessment, it may be appropriate to assume a 14-day weathering half-life (used for forage in pasture/cow/milk pathway) pending further evaluation. In this case, the effective "days of intake" is 20 days. A combination of radioactive decay and weathering would result in an effective half-life for iodine–131 of 5 days and reduce the "days of intake" to 7 days.

(*c*) In the case of a food which is sold in the retail market, the effective "days of intake" would probably be limited by the quantity purchased at a given time. For most food, especially fresh produce, this would probably be about a 1 week supply. In some cases, however, larger quantities would be purchased for home canning or freezing. For most foods and members of the public, an effective "days of intake" 30 days is probably conservative.

(iii) For population groups having significantly different dietary intakes, an appropriate adjustment of dietary factors should be made.

(2) *Radionuclide mixtures.* If a mixture of radionuclides is present, the sum of all the ratios of the concentration of each specific radionulide to its specific response level equivalent to the PAG should be less than one.

(3) *Other radionuclides.* The response level for the Preventive and Emergency PAG for other radionuclides should be calculated from dose commitment factors available in the literature (Killough, G. G., et al., ORNL/NUREG/TM–190 (1978) (adult only), and U.S. Nuclear Regulatory Commission Reg. Guide 1.109 (1977)).

(4) *Other critical organs.* Dose commitment factors in U.S. Nuclear Regulatory Commission Reg. Guide 1.109 (1977) refer to bone rather than bone marrow dose commitments. For the purpose of these recommendations, dose commitment to the bone marrow is considered to be 0.3 of the bone dose commitment. This is based on the ratio of dose rate per unit activity in the bone marrow to dose rate per unit activity in a small tissue-filled cavity in bone and assumes that strontium–90 is distributed only in the mineral bone (Spiers, F. W., et al., *in* "Biomedical Implications of Radiostrontium Exposure," AEC Symposium 25 (1972). The ratio for strontium–89 is the same because the mean particle energies are similar (0.56 MeV (megaelectronvolts)). Situations could arise in which an organ other than those discussed in this paragraph could

be considered to be the organ receiving the highest dose per unit intake. In the case of exposure via the food chain, depending on the radionuclide under consideration, the gastrointestinal tract could be the primary organ exposed. The references cited in paragraph (e)(3) of these recommendations contain dose commitment factors for the following organs: bone, kidneys, liver, ovaries, spleen, whole body, and gastrointestinal tract.

(5) Prompt notification of State and local agencies regarding the occurrence of an incident having potential public health consequences is of significant value in the implementation of effective protective actions. Such notification is particularly important for protective actions to prevent exposures from the airborne cloud but is also of value for food pathway contamination. Accordingly, this protective action guidance should be incorporated in State/local emergency plans which provide for coordination with nuclear facility operators including prompt notification of accidents and technical communication regarding public health consequences and protective action.

(f) *Sampling parameter.* Generally, sites for sample collection should be the retail market, the processing plant, and the farm. Sample collection at the milk processing plant may be more effcient in determining the extent of the food pathway contamination. The geographic area where protective actions are implemented should be based on considerations of the wind direction and atmospheric transport, measurements by airborne and ground survey teams of the radioactive cloud and surface deposition, and measurements in the food pathway.

(g) *Recommended methods of analysis.* Techniques for measurement of radionuclide concentrations should have detection limits equal to or less than the response levels equivalent to specific PAG. Some useful methods of radionuclide analysis can be found in:

(1) *Laboratory Methods*—"HASL Procedure Manual," edited by John H. Harley, HASL 300 ERDA, Health and Safety Laboratory, New York, NY, 1973; "Rapid Methods for Estimating Fission Product Concentrations in Milk," U.S. Department of Health, Education, and Welfare, Public Health Service Publication No. 999–R–2, May 1963; "Evaluation of Ion Exchange Cartridges for Field Sampling of Iodine–131 in Milk," Johnson, R. H. and T. C. Reavy, *Nature*, 208, (5012): 750–752, November 20, 1965; and

(2) *Field Methods*—Kearny, C. H., ORNL 4900, November 1973; Distenfeld, C. and J. Klemish, Brookhaven National Laboratory, NUREG/CR–0315, December 1978; and International Atomic Energy Agency, "Environmental Monitoring in Emergency Situations," 1966. Analysis need not be limited to these methodologies but should provide comparable results. Action should not be taken without verification of the analysis. Such verification might include the analysis of duplicate samples, laboratory measurements, sample analysis by other agencies, sample analysis of various environmental media, and descriptive data on radioactive release.

(h) *Protective actions.* Actions are appropriate when the health benefit associated with the reduction in dose that can be achieved is considered to offset the undesirable health, economic, and social factors. It is the intent of these recommendations that, not only the protective actions cited for the Emergency PAG be initiated when the equivalent response levels are reached, but also that actions appropriate at the Preventive PAG be considered. This has the effect of reducing the period of time required during which the protective action with the greater economic and social impact needs to be taken. FDA recommends that once one or more protective actions are initiated, the action or actions continue for a sufficient time to avoid most of the projected dose. There is a longstanding FDA policy that the purposeful blending of adulterated food with unadulterated food is a violation of the Federal Food, Drug, and Cosmetic Act. The following protective actions should be considered for implementation when the projected dose equals or exceeds the appropriate PAG:

(1) *Preventive PAG.* (i) For pasture: (*a*) Removal of lactating dairy cows from contaminated pasturage and substitution of uncontaminated stored feed.

(*b*) Substitute source of uncontaminated water.

(ii) For milk: (*a*) Withholding of contaminated milk from the market to allow radioactive decay of short-lived radionuclides. This may be achieved by storage of frozen fresh milk, frozen concentrated milk, or frozen concentrated milk products.

(*b*) Storage for prolonged times at reduced temperatures also is feasible provided ultrahigh temperature pasteurization techniques are employed for processing (Finley, R. D., H. B. Warren, and R. E. Hargrove, "Storage Stability of Commercial Milk," *Journal of Milk and Food Technology*, 31(12):382–387, December 1968).

(*c*) Diversion of fluid milk for production of dry whole milk, nonfat dry milk, butter, cheese, or evaporated milk.

(iii) For fruits and vegetables: (*a*) Washing, brushing, scrubbing, or peeling to remove surface contamination.

(*b*) Preservation by canning, freezing, and dehydration or storage to permit radioactive decay of short-lived radionuclides.

(iv) For grains: (*a* Milling and (*b*) polishing.

(v) For other food products, processing to remove surface contamination.

(vi) For meat and meat products, intake of cesium-134 and cesium-137 by an adult via the meat pathway may exceed that of the milk pathway; therefore, levels of cesium in milk approaching the "response level" should cause surveillance and protective actions for meat as appropriate.

(vii) For animal feeds other than pasture, action should be on a case-by-case basis taking into consideration the relationship between the radionuclide concentration in the animal feed and the concentration of the radionuclide in human food. For hay and silage fed to lactating cows, the concentration should not exceed that equivalent to the recommendations for pasture.

(2) *Emergency PAG.* Responsible officials should isolate food containing radioactivity to prevent its introduction into commerce and determine whether condemnation or another disposition is appropriate. Before taking this action, the following factors should be considered:

(i) The availability of other possible protective actions discussed in paragraph (h)(1) of these recommendations.

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

(iii) The importance of the particular food in nutrition and the availability of uncontaminated food or substitutes having the same nutritional properties.

(iv) The relative contribution of other foods and other radionuclides to the total projected dose.

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

This notice is issued under the Public Health Service Act (secs. 301, 310, 311, 58 Stat. 691–693 as amended, 88 Stat. 371 (42 U.S.C. 241, 242o, 243)) and under authority delegated to the Commissioner of Food and Drugs (21 CFR 5.10).

Dated: October 11, 1982.

Arthur Hull Hayes, Jr.,

Commissioner of Food and Drugs.

[FR Doc. 82–28595 Filed 10–21–82; 8:45 am]

BILLING CODE 4160–01–M

CHAPTER 4

Protective Action Guides for the Intermediate Phase (Deposited Radioactive Materials)

4.1 Introduction

Following a nuclear incident it may be necessary to temporarily relocate the public from areas where extensive deposition of radioactive materials has occurred until decontamination has taken place. This chapter identifies the levels of radiation exposure which indicate when relocation from contaminated property is warranted.

The period addressed by this chapter is denoted the "intermediate phase." This is arbitrarily defined as the period beginning after the source and releases have been brought under control and environmental measurements are available for use as a basis for decisions on protective actions and extending until these protective actions are terminated. This phase may overlap the early and late phases and may last from weeks to many months. For the purpose of dose projection, it is assumed to last for one year. Prior to this period protective actions will have been taken based upon the PAGs for the early phase. It is assumed that decisions will be made during the intermediate phase concerning whether particular areas or properties from which persons have been relocated will be decontaminated and reoccupied, or condemned and the occupants permanently relocated. These actions will be carried out during the late or "recovery" phase.

Although these Protective Action Guides (PAGs) were developed based on expected releases of radioactive materials characteristic of reactor incidents, they may be applied to any type of incident that can result in long-term exposure of the public to deposited radioactivity.

PAGs are expressed in terms of the projected doses above which specified protective actions are warranted. In the case of deposited radioactivity, the major relevant protective action is relocation. Persons not relocated (i.e., those in less contaminated areas) may reduce their dose through the application of simple decontamination techniques and by spending more time than usual in low exposure rate areas (e.g., indoors).

The PAGs should be considered mandatory only for use in planning, e.g., in developing radiological emergency response plans. During an incident, because of unanticipated local conditions and constraints, professional judgment by responsible officials will be required in their application. Situations can be envisaged, where contamination from a nuclear incident

occurs at a site or time in which relocation of the public, based on the recommended PAGs, would be impracticable. Conversely, under some conditions, relocation may be quite practicable at projected doses below the PAGs. These situations require judgments by those responsible for protective action decisions at the time of the incident. A discussion of the implementation of these PAGs is provided in Chapter 7.

The PAGs for relocation specified in this chapter refer only to estimates of doses due to exposure during the first year after the incident. Exposure pathways include external exposure to radiation from deposited radioactivity and inhalation of resuspended radioactive materials. Protective Action Guides for ingestion exposure pathways, which also apply during the intermediate phase, are discussed separately in Chapter 3.

Individuals who live in areas contaminated by long-lived radionuclides may be exposed to radiation from these materials, at a decreasing rate, over the entire time that they live in the area. This would be the case for those who are not relocated as well as for persons who return following relocation. Because it is usually not practicable, at the time of a decision to relocate, to calculate the doses that might be incurred from exposure beyond one year, and because different protective actions may be appropriate over such longer periods of time, these doses are not included in the dose specified in the PAGs for relocation.

4.1.1 Exposure Pathways

The principal pathways for exposure of the public occupying locations contaminated by deposited radioactivity are expected to be exposure of the whole body to external gamma radiation from deposited radioactive materials (groundshine) and internal exposure from the inhalation of resuspended materials. For reactor incidents, external gamma radiation is expected to be the dominant source.

Almost invariably relocation decisions will be based on doses from the above pathways. (However, in rare cases where food or drinking water is contaminated to levels above the PAG for ingestion, and its withdrawal from use will create a risk from starvation greater than that from the radiation dose, the dose from ingestion should be added to the dose from the above pathways.) PAGs related specifically to the withdrawal of contaminated food and water from use are discussed in Chapter 3.

Other potentially significant exposure pathways include exposure to beta radiation from surface contamination and direct ingestion of contaminated soil. These pathways are not expected to be controlling for reactor incidents (AR-89).

4.1.2 The Population Affected

The PAGs for relocation are intended for use in establishing the boundary of a restricted zone within an

area that has been subjected to deposition of radioactive materials. During their development, consideration was given to the higher risk of effects on health to children and fetuses from radiation dose and the higher risk to some other population groups from relocation. To avoid the complexity of implementing separate PAGs for individual members of the population, the relocation PAG is established at a level that will provide adequate protection for the general population.

Persons residing in contaminated areas outside the restricted zone will be at some risk from radiation dose. Therefore, guidance on the reduction of dose during the first year to residents outside this zone is also provided. Due to the high cost of relocation, it is more practical to reduce dose in this population group by the early application of simple, low-impact, protective actions other than by relocation.

4.2 The Protective Action Guides for Deposited Radioactivity

PAGs for protection from deposited radioactivity during the intermediate phase are summarized in Table 4-1. The basis for these values is presented in detail in Appendix E. In summary, relocation is warranted when the projected sum of the dose equivalent from external gamma radiation and the committed effective dose equivalent from inhalation of resuspended radionuclides exceeds 2 rem in the first year. Relocation to avoid exposure of the skin to beta radiation is warranted at 50 times the numerical value of the relocation PAG for effective dose equivalent.

Persons who are not relocated, i.e., those in areas that receive relatively small amounts of deposited radioactive material, should reduce their exposure by the application of other measures. Possible dose reduction techniques range from the simple processes of scrubbing and/or flushing surfaces, soaking or plowing of soil, removal and disposal of small spots of soil found to be highly contaminated (e.g., from settlement of water), and spending more time than usual in lower exposure rate areas (e.g., indoors), to the difficult and time-consuming processes of removal, disposal, and replacement of contaminated surfaces. It is anticipated that simple processes will be most appropriate for early application. Many can be carried out by residents themselves with support from response officials for assessment of the levels of contamination, guidance on appropriate actions, and disposal of contaminated materials. Due to the relatively low cost and risk associated with these protective actions, they may be justified as ALARA measures at low dose levels. It is, however, recommended that response officials concentrate their initial efforts in areas where the projected dose from the first year of exposure exceeds 0.5 rem. In addition, first priority should be given to cleanup of residences of pregnant women who may exceed this criterion.

Table 4-1 Protective Action Guides for Exposure to Deposited Radioactivity During the Intermediate Phase of a Nuclear Incident

Protective Action	PAG (projected dose)[a]	Comments
Relocate the general population.[b]	≥2 rem	Beta dose to skin may be up to 50 times higher
Apply simple dose reduction techniques.[c]	<2 rem	These protective actions should be taken to reduce doses to as low as practicable levels.

[a]The projected sum of effective dose equivalent from external gamma radiation and committed effective dose equivalent from inhalation of resuspended materials, from exposure or intake during the first year. Projected dose refers to the dose that would be received in the absence of shielding from structures or the application of dose reduction techniques. These PAGs may not provide adequate protection from some long-lived radionuclides (see Section 4.2.1).

[b]Persons previously evacuated from areas outside the relocation zone defined by this PAG may return to occupy their residences. Cases involving relocation of persons at high risk from such action (e.g., patients under intensive care) should be evaluated individually.

[c]Simple dose reduction techniques include scrubbing and/or flushing hard surfaces, soaking or plowing soil, minor removal of soil from spots where radioactive materials have concentrated, and spending more time than usual indoors or in other low exposure rate areas.

4.2.1 Longer Term Objectives of the Protective Action Guides

It is an objective of these PAGs to assure that 1) doses in any single year after the first will not exceed 0.5 rem, and 2) the cumulative dose over 50 years (including the first and second years) will not exceed 5 rem. For source terms from reactor incidents, the above PAG of 2 rem projected dose in the first year is expected to meet both of those objectives through radioactive decay, weathering, and normal part time occupancy in structures. Decontamination of areas outside the restricted area may be required during the first year to meet these objectives for releases consisting primarily of long-lived radionuclides. For situations where it is impractical to meet these objectives though decontamination, consideration should be given to relocation at a lower projected first year dose than that specified by the relocation PAG.

After the population has been protected in accordance with the PAGs for relocation, return for occupancy of previously restricted areas should be governed on the basis of Recovery Criteria as presented in Chapter 8.

Projected dose considers exposure rate reduction from radioactive decay and, generally, weathering. When one also considers the anticipated effects of shielding from partial occupancy in homes and other structures, persons who are not relocated should receive a dose substantially less than the projected dose. For commonly assumed reactor source terms, we estimate that 2 rem projected dose in the first year will be reduced to about 1.2 rem by this factor. The application of simple decontamination techniques shortly after the incident can be assumed to provide a further 30 percent or more reduction, so that the maximum first year dose to persons who are not relocated is expected to be less than one rem. Taking account of decay rates assumed to be associated with releases from nuclear power plant incidents (SN-82) and shielding from partial occupancy and weathering, a projected dose of 2 rem in the first year is likely to amount to an actual dose of 0.5 rem or less in the second year and 5 rem or less in 50 years. The application of simple dose reduction techniques would reduce these doses further. Results of calculations supporting these projections are summarized in Table E-6 of Appendix E.

4.2.2 Applying the Protective Action Guides for Relocation

Establishing the boundary of a restricted zone may result in three different types of actions:

1. Persons who, based on the PAGs for the early phase of a nuclear incident (Chapter 2), have already been evacuated from an area which is now designated as a restricted zone must be converted to relocation status.

2. Persons not previously evacuated who reside inside the restricted zone should relocate.

3. Persons who normally reside outside the restricted zone, but were previously evacuated, may return. A gradual return is recommended, as discussed in Chapter 7.

Small adjustments to the boundary of the restricted zone from that given by the PAG may be justified on the basis of difficulty or ease of implementation. For example, the use of a convenient natural boundary could be cause for adjustment of the restricted zone. However, such decisions should be supported by demonstration that exposure rates to persons not relocated can be promptly reduced by methods other than relocation to meet the PAG, as well as the longer term dose objectives addressed in Section 4.2.1.

Reactor incidents involving releases of major portions of the core inventory under adverse atmospheric conditions can be postulated for which

large areas would have to be restricted under these PAGs. As the affected land area increases, they will become more difficult and costly to implement, especially in densely populated areas. For situations where implementation becomes impracticable or impossible (e.g., a large city), informed judgment must be exercised to assure priority of protection for individuals in areas having the highest exposure rates. In such situations, the first priority for any area should be to reduce dose to pregnant women.

4.3 Exposure Limits for Persons Reentering the Restricted Zone

Individuals who are permitted to reenter a restricted zone to work, or for other justified reasons, will require protection from radiation. Such individuals should enter the restricted zone under controlled conditions in accordance with dose limitations and other procedures for control of occupationally-exposed workers (EP-87). Ongoing doses received by these individuals from living in a contaminated area outside the restricted zone need not be included as part of this dose limitation applicable to workers. In addition, dose received previously from the plume and associated groundshine, during the early phase of the nuclear incident, need not be considered.

References

AR-89 Aaberg, Rosanne, Evaluation of Skin and Ingestion Exposure Pathways. EPA 520/1-89-016. U.S. Environmental Protection Agency, Washington, (1989).

EP-87 U.S. Environmental Protection Agency. Radiation Protection Guidance to Federal Agencies for Occupational Exposure. Federal Register, 52, 2822; January 27, 1987.

SN-82 Sandia National Laboratory. Technical Guidance for Siting Criteria Development. NUREG/CR-2239. U.S. Nuclear Regulatory Commission, Washington, (1982).

CHAPTER 5

Implementing the Protective Action Guides for the Early Phase

5.1 Introduction

This chapter provides general guidance for implementing the Protective Action Guides (PAGs) set forth in Chapter 2. In particular, the objective is to provide guidance for estimating projected doses from exposure to an airborne plume of radioactive material, and for choosing and implementing protective actions.

Following an incident which has the potential for an atmospheric release of radioactive material, the responsible State and/or local authorities will need to decide whether offsite protective actions are needed and, if so, where and when they should be implemented. These decisions will be based primarily on (a) the potential for releases, (b) projected doses as a function of time at various locations in the environment, and (c) dose savings and risks associated with various protective actions.

Due to the wide variety of nuclear facilities, incidents, and releases that could occur, it is not practical to provide specific implementing guidance for all situations. Examples of the types of sources leading to airborne releases that this guidance may be applied to are nuclear power reactors, uranium fuel cycle facilities, nuclear weapons facilities, radiopharmaceutical manufacturers and users, space vehicle launch and reentry, and research reactors. For many specific applications, however, it will be appropriate to develop and use implementing procedures that are designed for use on a case-by-case basis.

Dose conversion factors (DCF) and derived response levels (DRL) are provided for radionuclides that are most likely to be important in an incident involving an airborne release of radioactive materials. DCFs and DRLs for radionuclides not listed may be developed from the sources referenced in the tables. The values provided here are the best currently available. However, as new information is developed these values may change. This chapter will be revised from time to time to reflect such changes.

5.2 Initial Response and Sequence of Subsequent Actions

In the case of an atmospheric release, the protective actions which may be required are those which protect the population from inhalation of radioactive materials in the plume, from exposure to gamma radiation

from the plume, and from short-term exposure to radioactive materials deposited on the ground. For releases which contain a large amount of pure beta emitters, it may also be necessary to consider protective action to avoid doses to the skin from radioactive material deposited on the skin and clothing.

The early phase can be divided into two periods: (a) the period immediately following the start of an incident (possibly before a release has occurred), when little or no environmental data are available to confirm the magnitude of releases, and (b) the subsequent period, when environmental or source term measurements permit a more accurate assessment of projected doses.

During the first period, speed in completing such actions as evacuating, sheltering, and controlling access may be critical to minimizing exposure. Environmental measurements made during this period may have limited use because of the lack of availability of significant data and uncertainty about changes in environmental releases of radioactive material from their sources. In the case of a facility, for example, the uncertainty might be due to changes in pressure and radionuclide concentrations within the structures from which the plume is being released. Therefore, it is advisable to initiate early protective actions in a predetermined manner that is related to facility conditions. This will normally be carried out through recommendations provided by the facility operator. During the second period, when environmental levels are known, these actions can be adjusted as necessary.

For an incident at a facility involving significant potential for an atmospheric release with offsite consequences, the following sequence of actions is appropriate:

1. Notification of State and/or local authorities by the facility operator that conditions are such that a release is occurring, or could occur with offsite consequences. For severe incidents (e.g., general emergencies) the operator should provide protective action recommendations to State and local authorities.[1]

2. For emergencies with the potential for offsite consequences, immediate evacuation (and/or sheltering) of populations in predesignated areas without waiting for release rate information or environmental measurements.

3. Monitoring of facility conditions, release rates, environmental concentrations, and exposure rates.

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[1]In the case of commercial nuclear power plants, fuel facilities and certain material facilities licensed by the NRC, regulations (NR-89) require that the facility operator have the capability to notify predesignated State and/or local authorities within 15 minutes of any emergency declaration. The initial notification message to State and/or local officials for any General Emergency declaration must include a protective action recommendation.

4. Estimation of offsite consequences (e.g., calculation of the plume centerline dose rates and projected doses at various distances downwind from the release point).

5. Implementation of protective actions in additional areas if needed.

6. Decisions to terminate existing protective actions should include, as a minimum, consideration of the status of the plant and the PAGs for relocation (Chapter 4). (Withdrawal of protective actions from areas where they have already been implemented is usually not advisable during the early phase because of the potential for changing conditions and confusion.)

For other types of incidents the sequence of actions may vary in details, depending on the specific emergency response plan, but in general the sequence and general reporting requirements will be the same.

5.2.1 Notification

The nuclear facility operator or other designated individual should provide the first notification to State and/or local authorities that a nuclear incident has occurred. In the case of an incident with the potential for offsite consequences, notification of State and local response organizations by a facility operator should include recommendations, based on plant conditions, for early evacuation and/or sheltering in predesignated areas. Early estimates of the various components of projected doses to the population at the site boundary, as well as at more distant locations, along with estimated time frames, should be made as soon as the relevant source or release data become available. Emergency response planners should make arrangements with the facility operator to assure that this information will be made available on a timely basis and that dose projections will be provided in units that can be directly compared to the PAGs. Planners should note that the toxic chemical hazard is greater than the radiation hazard for some nuclear incidents, e.g. a uranium hexafluoride release.

For some incidents, such as re-entry of satellites or an incident in a foreign country, notification is most likely to occur through the responsible Federal agency, most commonly the Environmental Protection Agency or the National Aeronautics and Space Administration. In such cases projections of dose and recommendations to State and local officials for protective actions will be made at the Federal level, under the Federal Radiological Emergency Response Plan (FE-85).

5.2.2 Immediate Protective Action

Guidance for developing emergency response plans for implementation of immediate protective actions for incidents at commercial nuclear power plants is contained in NUREG-0654 (NR-80). Planning elements for

incidents at other types of nuclear facilities should be developed using similar considerations. Information on the offsite consequences of accidents that can occur at commercial fuel cycle and material facilities licensed by the NRC can be found in NUREG-1140 (NR-88). The "Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants" (NR-78) recommends that States designate an emergency planning zone (EPZ) for protective action for plume exposure (see Chapter 2). Within this zone, an area should be predesignated for immediate response based on specified plant conditions prior to a release, or, given a release, prior to the availability of information on quantities of radioactive materials released. The shape of this area will depend on local topography and political and other boundaries. Additional areas in the balance of the EPZ, particularly in the downwind direction, may also require evacuation or sheltering, as determined by dose projections. The size of these areas will be based on the potential magnitude of the release, and of an angular spread determined by meteorological conditions and any other relevant factors.

The predesignated areas for immediate protective action may be reserved for use only for the most severe incidents and where the facility operator cannot provide a quick estimate of projected dose based on actual releases. For lesser incidents, or if the facility operator is able to provide prompt offsite dose projections, the area for immediate protective action may be specified at the time of the incident, in lieu of using a predesignated area.

Such prompt offsite dose projections may be possible when the facility operator can estimate the potential offsite dose, based on information at the facility, using relationships developed during planning that relate abnormal plant conditions and meteorological conditions to potential offsite doses. After the release starts and the release rate is measurable and/or when plant conditions or measurements can be used to estimate the characteristics of the release and the release rate as a function of time, then these factors, along with atmospheric stability, windspeed, and wind direction, can be used to estimate integrated concentrations of radioactive contamination as a function of location downwind. Although such projections are useful for initiating protective action, the accuracy of these methods for estimating projected dose will be uncertain prior to confirmatory field measurements because of unknown or uncertain factors affecting environmental pathways, inadequacies of computer modeling, and uncertainty in the data for release terms.

5.3 The Establishment of Exposure Patterns

During and immediately following the early response to a nuclear incident, sufficient environmental

measurements are unlikely to be available to project doses accurately. Doses must be projected using initial environmental measurements or estimates of the source term, and using atmospheric transport previously observed under similar meteorological conditions. These projections are needed to determine whether protective actions should be implemented in additional areas during the early phase.

Source term measurements, or exposure rates or concentrations measured in the plume at a few selected locations, may be used to estimate the extent of the exposed area in a variety of ways, depending on the types of data and computation methods available. The most accurate method of projecting doses is through the use of an atmospheric diffusion and transport model that has been verified for use at the site in question. A variety of computer software can be used to estimate exposures in real time, or to extrapolate a series of previously-prepared isopleths for unit releases under various meteorological conditions. The latter can be adjusted for the estimated source magnitude or environmental measurements at a few locations during the incident. If the model projections have some semblance of consistency with environmental measurements, extrapolation to other distances and areas can be made with greater confidence. If projections using a sophisticated site-specific model are not available, a simple, but crude, method is to measure the plume centerline exposure rate[2] at ground level (approximately one meter height) at a known distance downwind of the release point and then to calculate exposure rates at other downwind locations by assuming that the plume centerline exposure rate is a known function of the distance from the release point.

The following relationship can be used for this calculation:

$$D_2 = D_1 (R_1/R_2)^y \ ,$$

where D_1 and D_2 are measurements of exposure rates at the centerline of the plume at distances R_1 and R_2, respectively, and y is a constant that depends on atmospheric stability. For stability classes A and B, y = 2; for stability classes C and D, y = 1.5; and for stability classes E and F, y = 1. Classes A and B (unstable) occur with light winds and strong sunlight, and classes E and F (stable) with light winds at night. Classes C and D generally occur with winds stronger than about 10 mph. This method of extrapolation is risky because the measurements available at the reference distance may be unrepresentative, especially if the plume is aloft and has a looping

[2]The centerline exposure rate can be determined by traversing the plume at a point sufficiently far downwind that it has stabilized (usually more than one mile from the release point) while taking continuous exposure rate measurements.

behavior. In the case of an elevated plume, the ground level concentration increases with distance from the source, and then decreases, whereas any high energy gamma radiation from the overhead cloud continuously decreases with distance. For these reasons, this method of extrapolation will perform best for surface releases or if the point of measurement for an elevated release is sufficiently distant from the point of release for the plume to have expanded to ground level (usually more than one mile). The accuracy of this method will be improved by the use of measurements from many locations averaged over time.

5.4 Dose Projection

The PAGs set forth in Chapter 2 are specified in terms of the effective dose equivalent. This dose includes that due to external gamma exposure of the whole body, as well as the committed effective dose equivalent from inhaled radionuclides. Guidance is also provided on protective action levels for the thyroid and skin, in terms of the committed dose equivalent to these organs. Further references to effective or organ dose equivalent refer to these two quantities, respectively. Methods for estimating projected doses for each of these forms of exposure are discussed below. These require knowledge of, or assumptions for, the intensity and duration of exposure and make use of standard assumptions on the relation, for each radioisotope, between exposure and dose. Exposure and dose projections should be based on the best estimates available. The methods and models used here may be modified as necessary for specific sites to achieve improved accuracy.

5.4.1 Duration of Exposure

The projected dose for comparison to the early phase PAGs is normally calculated for exposure during the first four days following the projected (or actual) start of a release. The objective is to encompass the entire period of exposure to the plume and to deposited material prior to implementation of any further, longer-term protective action, such as relocation. Four days is chosen here as the duration of exposure to deposited materials during the early phase because, for planning purposes; it is a reasonable estimate of the time needed to make measurements, reach decisions, and prepare to implement relocation. However, officials at the site at the time of the emergency may decide that a different time is more appropriate. Corresponding changes to the dose conversion factors found in tables in Section 5.4.2 will be needed if another exposure period is selected.

Protective actions are taken to avoid or reduce projected doses. Doses incurred before the start of the protective action being considered should not normally be included in evaluating the need for protective action. Likewise, doses that may be incurred at later times than those affected by the specific protective action should not be included. For

example, doses which may be incurred through ingestion pathways or long-term exposure to deposited radioactive materials take place over a different, longer time period. Protective actions for such exposures should be based on guidance addressed in other chapters.

The projected dose from each radionuclide in a plume is proportional to the time-integrated concentration of the radionuclide in the plume at each location. This concentration will depend on the rate and the duration of the release and meteorological conditions. Release rates will vary with time, and this time-dependence cannot usually be predicted accurately. In the absence of more specific information, the release rate may be assumed to be constant.

Another factor affecting the estimation of projected dose is the duration of the plume at a particular location. For purposes of calculating projected dose from most pathways, exposure will start at a particular location when the plume arrives and end when the plume is no longer present, due either to an end to the release, or a change in wind direction. Exposure from one pathway (whole body exposure to deposited materials) will continue for an extended period. Other factors such as the aerodynamic diameter and solubility of particles, shape of the plume, and terrain may also affect estimated dose, and may be considered on a site- and/or source-specific basis.

Prediction of time frames for releases is difficult because of the wide range associated with the spectrum of potential incidents. Therefore, planners should consider the possible time periods between an initiating event and arrival of a plume, and the duration of releases in relation to the time needed to implement competing protective actions (i.e., evacuation and sheltering). Analyses of nuclear power reactors (NR-75) have shown that some incidents may take several days to develop to the point of a release, while others may begin as early as one-half hour after an initiating event. Furthermore, the duration of a release may range from less than one hour to several days, with the major portion of the release usually occurring within the first day.

Radiological exposure rates are quite sensitive to the wind speed. The air concentration is inversely related to the wind speed at the point of release. Concentrations are also affected by the turbulence of the air, which tends to increase with wind speed and sunlight, and by meandering of the plume, which is greater at the lower wind speeds. This results in higher concentrations generally being associated with low winds near the source, and with moderate winds at larger distances. Higher windspeed also shortens the travel time. Planning information on time frames for releases from nuclear power facilities may be found in Reference NR-78. Time frames for releases from other facilities will depend on the characteristics of the facility.

Since a change in wind direction will also affect the duration of exposure, it is very important that arrangements be made for a public, private, or military professional weather service to provide information on current meteorological and wind conditions and predicted wind direction persistence during an incident, in addition to information received from the facility operator.

5.4.2 Dose Conversion Factors

This section provides dose conversion factors (DCFs) and derived response levels (DRLs) for those radionuclides important for responding to most types of incidents. These are supplemented by an example to demonstrate their application. The DCFs are useful where multiple radionuclides are involved, because the total dose from a single exposure pathway will be the sum of the doses calculated for each radionuclide. The DRLs are surrogates for the PAG and are directly usable for releases consisting primarily of a single nuclide, in which case the DRL can be compared directly to the measured or calculated concentration. (DRLs also can be used for multiple radionuclides by summing the ratios of the environmental concentration of each nuclide to its respective DRL. To meet the PAG, this sum must be equal to or less than unity.)

DCFs and DRLs for each of the three major exposure pathways for the early phase (external exposure to plume, plume inhalation, and external exposure from deposited materials) are provided separately in Section 5.6. They are all expressed in terms of the time-integrated air concentration at the receptor so they can be conveniently summed over the three exposure pathways to obtain composite DRLs and DCFs for each radionuclide. These composite values are tabulated in Table 5-1 for effective dose and in Table 5-2 for thyroid dose from inhalation of radioiodines.

The tabulated DCFs and DRLs include assumptions on particle size, deposition velocity, the presence of short-lived daughters, and exposure duration as noted. The existence of more accurate data for individual radionuclides may justify modification of the DCFs and DRLs. The procedures described in Section 5.6 for developing the DCFs and DRLs for individual exposure pathways may be referred to, to assist such modifications.

To apply Tables 5-1 and 5-2 to decisions on implementing PAGs, one may use either the DCFs or DRLs. DCFs are used to calculate the projected composite dose for each radionuclide; these doses are then summed and compared to the PAG. The DRLs may be used by summing the ratios of the concentration of each radionuclide to its corresponding DRL. If the sum of the ratios exceeds unity, the corresponding protective action should be initiated.

Table 5-1 Dose Conversion Factors (DCF) and Derived Response Levels (DRL) for Combined[a] Exposure Pathways During the Early Phase of a Nuclear Incident[b]

Radionuclide	DCF rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[c] $\mu Ci \cdot cm^{-3} \cdot h$
H-3	7.7E+01	1.3E-02
C-14	2.5E+03	4.0E-04
Na-22	1.9E+04	5.3E-05
Na-24	7.3E+03	1.4E-04
P-32	1.9E+04	5.4E-05
P-33	2.8E+03	3.6E-04
S-35	3.0E+03	3.4E-04
Cl-36	2.6E+04	3.8E-05
K-40	1.6E+04	6.5E-05
K-42	2.0E+03	5.1E-04
Ca-45	8.0E+03	1.3E-04
Sc-46	4.4E+04	2.3E-05
Ti-44	1.2E+06	8.2E-07
V-48	2.4E+04	4.2E-05
Cr-51	5.5E+02	1.8E-03
Mn-54	1.2E+04	8.5E-05
Mn-56	1.8E+03	5.7E-04
Fe-55	3.2E+03	3.1E-04
Fe-59	2.3E+04	4.4E-05
Co-58	1.7E+04	5.7E-05
Co-60	2.7E+05	3.7E-06
Ni-63	7.6E+03	1.3E-04
Cu-64	5.9E+02	1.7E-03
Zn-65	2.7E+04	3.7E-05
Ge-68	6.2E+04	1.6E-05
Se-75	1.2E+04	8.3E-05
Kr-85	1.3E+00	7.8E-01
Kr-85m	9.3E+01	1.1E-02
Kr-87	5.1E+02	2.0E-03
Kr-88	1.3E+03	7.8E-04

Table 5-1, Continued

Radionuclide	DCF rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[c] $\mu Ci \cdot cm^{-3} \cdot h$
Kr-89	1.2E+03	8.6E-04
Rb-86	8.3E+03	1.2E-04
Rb-88	5.2E+02	1.9E-03
Rb-89	1.4E+03	7.3E-04
Sr-89	5.0E+04	2.0E-05
Sr-90	1.6E+06	6.4E-07
Sr-91	2.4E+03	4.2E-04
Y-90	1.0E+04	9.9E-05
Y-91	5.9E+04	1.7E-05
Zr-93	3.9E+05	2.6E-06
Zr-95	3.2E+04	3.2E-05
Zr-97	5.5E+03	1.8E-04
Nb-94	5.0E+05	2.0E-06
Nb-95	1.0E+04	9.7E-05
Mo-99	5.2E+03	1.9E-04
Tc-99	1.0E+04	1.0E-04
Tc-99m	1.7E+02	6.0E-03
Ru-103	1.3E+04	7.7E-05
Ru-105	1.2E+03	8.2E-04
Ru/Rh-106[d]	5.7E+05	1.7E-06
Pd-109	1.3E+03	7.6E-04
Ag-110m	9.8E+04	1.0E-05
Cd-109	1.4E+05	7.3E-06
Cd-113m	1.8E+06	5.5E-07
In-114m	1.1E+05	9.4E-06
Sn-113	1.3E+04	7.8E-05
Sn-123	3.9E+04	2.6E-05
Sn-125	2.0E+04	5.1E-05
Sn-126	1.2E+05	8.4E-06
Sb-124	3.8E+04	2.6E-05

Table 5-1, Continued

Radionuclide	DCF rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[c] $\mu Ci \cdot cm^{-3} \cdot h$
Sb-126	2.6E+04	3.9E-05
Sb-127	9.5E+03	1.1E-04
Sb-129	2.0E+03	5.0E-04
Te-127m	2.6E+04	3.9E-05
Te-129	1.4E+02	7.0E-03
Te-129m	2.9E+04	3.5E-05
Te-131m	8.6E+03	1.2E-04
Te-132	1.2E+04	8.5E-05
Te/I-132[d]	2.0E+04	5.0E-05
Te-134	7.0E+02	1.4E-03
I-125	3.0E+04	3.3E-05
I-129	2.1E+05	4.8E-06
I-131	5.3E+04	1.9E-05
I-132[e]	4.9E+03	2.0E-04
I-133	1.5E+04	6.8E-05
I-134	3.1E+03	3.3E-04
I-135	8.1E+03	1.2E-04
Xe-131m	4.9E+00	2.0E-01
Xe-133	2.0E+01	5.0E-02
Xe-133m	1.7E+01	5.9E-02
Xe-135	1.4E+02	7.0E-03
Xe-135m	2.5E+02	4.1E-03
Xe-137	1.1E+02	9.3E-03
Xe-138	7.2E+02	1.4E-03
Cs-134	6.3E+04	1.6E-05
Cs-136	1.8E+04	5.6E-05
Cs/Ba-137[d]	4.1E+04	2.4E-05
Cs-138	1.6E+03	6.1E-04
Ba-133	1.1E+04	8.9E-05
Ba-139	2.3E+02	4.4E-03

Table 5-1, Continued

Radionuclide	DCF rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[c] $\mu Ci \cdot cm^{-3} \cdot h$
Ba-140	5.3E+03	1.9E-04
La-140	1.1E+04	8.8E-05
La-141	7.3E+02	1.4E-03
La-142	2.3E+03	4.3E-04
Ce-141	1.1E+04	9.0E-05
Ce-143	4.7E+03	2.1E-04
Ce-144	4.5E+05	2.2E-06
Ce/Pr-144[d]	4.5E+05	2.2E+06
Nd-147	8.8E+03	1.1E-04
Pm-145	3.7E+04	2.7E-05
Pm-147	4.7E+04	2.1E-05
Pm-149	3.6E+03	2.8E-04
Pm-151	2.8E+03	3.5E-04
Sm-151	3.6E+04	2.8E-05
Eu-152	2.7E+05	3.8E-06
Eu-154	3.5E+05	2.9E-06
Eu-155	5.0E+04	2.0E-05
Gd-153	2.9E+04	3.4E-05
Tb-160	3.5E+04	2.9E-05
Ho-166m	9.4E+05	1.1E-06
Tm-170	3.2E+04	3.2E-05
Yb-169	1.1E+04	8.9E-05
Hf-181	2.1E+04	4.8E-05
Ta-182	6.0E+04	1.7E-05
W-187	1.7E+03	6.0E-04
Ir-192	3.8E+04	2.7E-05
Au-198	5.2E+03	1.9E-04
Hg-203	9.9E+03	1.0E-04
Tl-204	2.9E+03	3.5E-04
Pb-210	1.6E+07	6.1E-08

Table 5-1, Continued

Radionuclide	DCF rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[c] $\mu Ci \cdot cm^{-3} \cdot h$
Bi-207	3.1E+04	3.2E-05
Bi-210	1.9E+04	5.3E-05
Po-210	1.1E+07	8.9E-08
Ra-226	1.0E+07	9.7E-08
Ac-227	8.0E+09	1.2E-10
Ac-228	3.7E+05	2.7E-06
Th-227	1.9E+07	5.2E-08
Th-228	4.1E+08	2.4E-09
Th-230	3.9E+08	2.6E-09
Th-232	2.0E+09	5.1E-10
Pa-231	1.5E+09	6.5E-10
U-232	7.9E+08	1.3E-09
U-233	1.6E+08	6.2E-09
U-234	1.6E+08	6.3E-09
U-235	1.5E+08	6.8E-09
U-236	1.5E+08	6.6E-09
U-238	1.4E+08	7.0E-09
U-240	2.7E+03	3.7E-04
Np-237	6.5E+08	1.5E-09
Np-239	3.6E+03	2.8E-04
Pu-236	1.7E+08	5.8E-09
Pu-238	4.7E+08	2.1E-09
Pu-239	5.2E+08	1.9E-09
Pu-240	5.2E+08	1.9E-09
Pu-241	9.9E+06	1.0E-07
Pu-242	4.9E+08	2.0E-09
Am-241	5.3E+08	1.9E-09
Am-242m	5.1E+08	2.0E-09
Am-243	5.3E+08	1.9E-09
Cm-242	2.1E+07	4.8E-08

Table 5-1, Continued

Radionuclide	DCF rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[c] $\mu Ci \cdot cm^{-3} \cdot h$
Cm-243	3.7E+08	2.7E-09
Cm-244	3.0E+08	3.4E-09
Cm-245	5.5E+08	1.8E-09
Cm-246	5.4E+08	1.9E-09
Cf-252	1.9E+08	5.3E-09

[a]Sum of doses from external exposure and inhalation from the plume, and external exposure from deposition. "Dose" means the sum of effective dose equivalent from external radiation and committed effective dose equivalent from intake.

[b]See footnote a to Table 5-4 for assumptions on inhalation and footnote b to Table 5-5 for assumptions on deposition velocity. The quantity $\mu Ci \cdot cm^{-3} \cdot h$ refers to the time-integrated air concentration at one meter height.

[c]For 1 rem committed effective dose equivalent.

[d]The contribution from the short-lived daughter is included in the factors for the parent radionuclide.

[e]These factors should only be used in situations where I-132 appears without the parent radionuclide.

Persons exposed to an airborne particulate plume will receive dose to skin from beta emitters in the plume as well as from those deposited on skin and clothing. Although it is possible to detect beta radiation, it is not practical, for purposes of decisions on evacuation and sheltering, to determine dose to skin by field measurement of the beta dose equivalent rate near the skin surface. Such doses are determined more practically through calculations based on time-integrated air concentration, an assumed deposition velocity, and an assumed time period between deposition and skin decontamination. For the purpose of evaluating the relative importance of skin dose compared to the dose from external gamma exposure and inhalation, dose conversion factors were evaluated using a deposition velocity of 1 cm/sec and an exposure time before decontamination of 12 hours. Using these conservative assumptions, it was determined that skin beta dose should seldom, if ever, be a controlling pathway during the early phase. Therefore, no DCFs or DRLs are listed for skin beta dose.

Table 5-2 Dose Conversion Factors (DCF) and Derived Response Levels (DRL) Corresponding to a 5 rem Dose Equivalent to the Thyroid from Inhalation of Radioiodine

Radionuclide	DCF rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[a] $\mu Ci \cdot cm^{-3} \cdot h$
Te/I-132[b]	2.9E+05	1.8E-05
I-125	9.6E+05	5.2E-06
I-129	6.9E+06	7.2E-07
I-131	1.3E+06	3.9E-06
I-132	7.7E+03	6.5E-04
I-133	2.2E+05	2.3E-05
I-134	1.3E+03	3.9E-03
I-135	3.8E+04	1.3E-04

[a]For a 5 rem committed dose equivalent to the thyroid.

[b]The contribution from the short-lived daughter is included in the factors for the parent radionuclide.

Because of large uncertainties in the assumptions for deposition, air concentrations are an inadequate basis for decisions on the need to decontaminate individuals. Field measurements should be used for this (See Chapter 7, Section 7.6.3.). It should be noted that, even in situations where the skin beta dose might exceed 50 rem, evacuation would not usually be the appropriate protective action, because skin decontamination and clothing changes are easily available and effective. However, evacuation would usually already be justified in these situations due to dose from inhalation during plume passage.

The following example demonstrates the use of the data in Tables 5-1 and 5-2 for a simple analysis involving three radionuclides.

Based on source term and meteorological considerations, it is assumed that the worst probable nuclear incident at an industrial facility is a fire that could disperse radioactive material into the atmosphere, yielding a time-integrated concentration of radionuclides at a nearby populated area, as follows:

Radionuclide	$\mu Ci \cdot cm^{-3} \cdot h$
Zr-95	2E-6
Cs-134	4E-8
I-131	1.2E-5

We examine whether evacuation is warranted at these levels, based on PAGs of 1 rem for effective dose and 5 rem for dose to the thyroid. We use the DCFs in Table 5-1 for effective dose and Table 5-2 for thyroid dose from inhalation of radioiodines to calculate the relevant doses, H, as follows:

$$H = \sum_{1}^{n} DCF_i \times C_i$$

where DCF_i = dose conversion factor for radionuclide i,
C_i = time-integrated concentration of radionuclide i,
and n = the number of radionuclides present.

For the committed effective dose equivalent (see Table 5-1):

(2 E-6 x 3.2E+4)+(4E-8 x 6.3 E+4)
+(1.2E-5 x 5.3E+4) = 0.71 rem.

For the committed dose equivalent to the thyroid (see Table 5-2):

1.2E-5 x 1.3E+6 = 16 rem.

The results of these calculations show that, at the location for which these time-integrated concentrations are specified, the committed dose equivalent to the thyroid from inhalation would be over three times the PAG for dose to thyroid, thus justifying evacuation. Using meteorological dilution factors, one could calculate the additional distance to which evacuation would be justified to avoid exceeding the PAG for thyroid dose.

To use the DRLs from Table 5-1 and 5-2, find the sum,

$$\sum_{1}^{n} \frac{C_i}{DRL_i}$$

for both effective dose and thyroid dose, where DRL_i is the derived response level for radionuclide i, and C_i is defined above. If the sum in either case is equal to or greater than unity, evacuation of the general population is warranted.

For effective dose (see Table 5-1):

$$\frac{2E-6}{3.2E-5} + \frac{4E-8}{1.6E-5} + \frac{1.2E-5}{1.9E-5} = 0.7$$

For dose to the thyroid (see Table 5-2):

$$\frac{1.2E-5}{3.9E-6} = 3$$

It is apparent that these calculations yield the same conclusions as those using the DCFs.

5.4.3 Comparison with Previously-Recommended PAGs

Many emergency response plans have already been developed using previously-recommended PAGs that apply to the dose equivalent to the whole body from direct (gamma) radiation from the plume and to the thyroid from inhalation of radioiodines. For nuclear power plant incidents, the

former PAG for whole body exposure provides public health protection comparable to that provided by the new PAG expressed in terms of effective dose equivalent. This is demonstrated in Table C-9 (Appendix C), which shows comparative doses for nuclear power plant fuel-melt accident sequences having a wide range of magnitudes. The PAG for the thyroid is unchanged. On the other hand, application of these PAGs to alpha emitting radionuclides leads to quite different derived response levels from those based on earlier health physics considerations, because of new dose conversion factors and the weighting factors assigned to the exposed organs (EP-88).

5.5 Protective Actions

This section provides guidance for implementing the principal protective actions (evacuation and sheltering) for protection against the various exposure pathways resulting from an airborne plume. Sheltering means the use of the closest available structure which will provide protection from exposure to an airborne plume, and evacuation means the movement of individuals away from the path of the plume.

Evacuation and sheltering provide different levels of dose reduction for the principal exposure pathways (inhalation of radioactive material, and direct gamma exposure from the plume or from material deposited on surfaces). The effectiveness of evacuation will depend on many factors, such as how rapidly it can be implemented and the nature of the accident. For accidents where the principal source of dose is inhalation, evacuation could increase exposure if it is implemented during the passage of a short-term plume, since moving vehicles provide little protection against exposure (DO-90). However, studies (NR-89a) continue to show that, for virtually all severe reactor accident scenarios, evacuation during plume passage does not increase the risk of acute health effects above the risk while sheltering. Sheltering, which in most cases can be almost immediately implemented, varies in usefulness depending upon the type of release, the shelter available, the duration of the plume passage, and climatic conditions.

Studies have been conducted to evaluate shelter (EP-78a) and evacuation (HA-75) as protective actions for incidents at nuclear power facilities. Reference EP-78b suggests one method for evaluating and comparing the benefits of these two actions. This requires collecting planning information before and data following an incident, and using calculations and graphical means to evaluate whether evacuation, sheltering, or a combination of sheltering followed by evacuation should be recommended at different locations. Because of the many interacting variables, the user is forced to choose between making decisions during the planning phase, based on assumed data that may be grossly inaccurate, or using a time-consuming more comprehensive process after the

incident when data may be available. In the former situation, the decision may not have a sound basis, whereas in the latter, the decision may come too late to be useful.

The recommended approach is to use planning information for making early decisions. The planned response should then be modified following the incident only if timely detailed information is available to support such modifications.

The planner should first compile the necessary information about the emergency planning zone (EPZ) around the facility. For the case of power reactors, some of this information is described in NUREG-0654 (NR-80). It should include identifying the population distribution, the sheltering effectiveness of residences and other structures, institutions containing population groups that require special consideration, evacuation routes, logical boundaries for evacuation zones, transportation systems, communications systems, and special problem areas. In addition, the planner should identify the information that may be available following an incident, such as environmental monitoring data, meteorological conditions, and plant conditions. The planner should identify key data or information that would justify specific protective actions. The evaluation and planning should also include the selection of institutions where persons should be provided with stable iodine for thyroid protection in situations where radioiodine inhalation is projected.

The following sections discuss key factors which affect the choice between evacuation and sheltering.

5.5.1 Evacuation

The primary objective of evacuation is to avoid exposure to airborne or deposited radioactive material by moving individuals away from the path of the plume. Evacuation, if completed before plume arrival, can be 100 percent effective in avoiding future exposure. Even if evacuation coincides with or follows plume passage, a large reduction of exposure may be possible. In any case, the maximum dose avoided by evacuation will be the dose not avoidable by sheltering.

Some general conclusions regarding evacuation (HA-75) which may be useful for planning purposes are summarized below:

1. Advanced planning is essential to identify potential problems that may occur in an evacuation.

2. Most evacuees use their own personal transportation.

3. Most evacuees assume the responsibility of acquiring food and shelter for themselves.

4. Evacuation costs are highly location-dependent and usually will not

be a deterrent to carrying out an evacuation.

5. Neither panic nor hysteria has been observed when evacuation of large areas is managed by public officials.

6. Large or small population groups can be evacuated effectively with minimal risk of injury or death.

7. The risk of injury or death to individual evacuees from transportation does not change as a function of the number of persons evacuated, and can be conservatively estimated using National Highway Safety Council statistics for motor vehicle accidents (subjective information suggests that the risks will be lower).

Evacuation of the elderly, the handicapped, and inhabitants of medical and other institutions may present special problems. When sheltering can provide adequate protection, this will often be the protective action of choice. However, if the general public is evacuated and those in institutions are sheltered, there is a risk that attendants at these institutions may leave and make later evacuation of institutionalized persons difficult because of a lack of attendants. Conversely, if evacuation of institutions is attempted during evacuation of the public, traffic conditions may cause unacceptable delays. If evacuation of institutions is attempted before evacuating the public, increased risk to the public from a delayed evacuation could occur, unless the incident is very slow in developing to the point of an atmospheric release. Because of the above difficulties, medical and other institutions located within the EPZ should be evaluated to determine whether there are any logical categories of persons that should be evacuated after the public (or, when time permits, before).

5.5.2 Sheltering

Sheltering refers here to the use of readily available nearby structures for protection against exposure to an airborne plume.

Sheltering may be an appropriate protective action because:

1. It positions the public to receive additional instructions when the possibility of high enough doses to justify evacuation exists, but is small.

2. It may provide protection equal to or greater than evacuation.

3. It is less expensive and disruptive than evacuation.

4. Since it may be implemented rapidly, sheltering may be the protective action of choice if rapid evacuation is impeded by, a) severe environmental conditions--e.g. severe weather or floods; b) health constraints--e.g. patients and workers in hospitals and nursing homes; or c) long mobilization times--certain industrial and farm workers, or prisoners and guards; d) physical

constraints to evacuation--e.g. inadequate roads.

5. Sheltering may be more effective against inhalation of radioactive particulates than against external gamma exposure, especially for short-term plumes.

The use of large structures, such as shopping centers, schools, churches, and commercial buildings, as collection points during evacuation mobilization will generally provide greater protection against gamma radiation than use of small structures.

As with evacuation, delay in taking shelter during plume passage will reduce the protection from exposure to radiation. The degree of protection provided by structures is governed by attenuation of gamma radiation by structural components (the mass of walls, ceilings, etc.) and by outside/inside air-exchange rates.

If external dose from the plume or from deposited materials is the controlling criterion, shelter construction and shelter size are the most important considerations; ventilation control and filtering are less important. Although sheltering will reduce the gamma exposure rate from deposited materials, it is not a suitable protective action for this pathway for long duration exposure. The main factors which reduce whole body exposure are:

1. Wall materials and thickness and size of structure,

2. Number of stories overhead, and

3. Use of a central location within the structure.

If a major release of radioiodine or respirable particulate materials occurs, inhalation dose will be the controlling pathway. For releases consisting primarily of noble gases, external gamma exposure will be most important. However, when inhalation is the primary exposure pathway, consideration should be given to the following:

1. Ventilation control is essential for effective sheltering.

2. Dose reduction factors for sheltering can be improved in several ways for the inhalation pathway, including reducing air exchange rates by sealing cracks and openings with cloth or weather stripping, tape, etc. Although the risk to health from the action could be a constraint (particularly for infants and the infirm), using wet towels or handkerchiefs as a mask to filter the inhaled air will reduce dose from inhalation.

3. Following plume passage, people should open shelters to reduce airborne activity trapped inside, and they should leave high exposure areas as soon as possible after cloud passage to avoid exposure to deposited radioactive material.

4. Consideration should be given to the prophylactic administration of potassium iodide (KI) as a

thyroid-blocking agent to workers performing emergency services and other groups in accordance with the PAGs in Table 2-1 and the provisions in reference FD-82.[3]

5.5.3 General Guidance for Evacuation and Sheltering

The process of evaluating, recommending, and implementing evacuation or shelter for the public is far from an exact science, particularly in view of time constraints that prevent thorough analysis at the time of an incident. Their effectiveness, however, can be improved considerably by planning and testing. Early decisions should be based on information collected from the emergency planning zone during the planning phase and on information regarding conditions at the nuclear facility at the time of the incident. Best estimates of dose projections should be used for decisions between evacuation and sheltering.

The following is a summary of planning guidance for evacuation and sheltering, based on the information in Sections 5.5.1 and 5.5.2.

1. For severe incidents, where PAGs may be significantly exceeded, evacuation may be the only effective protective action close to the facility.

2. Evacuation will provide total protection from any airborne release if it is completed before arrival of the plume.

3. Evacuation may increase exposure if carried out during the plume passage, for accidents involving inhalation dose as a major contributor.

4. Evacuation is also appropriate for protection from groundshine in areas with high exposure rates from deposited materials.

5. Sheltering may be appropriate (when available) for areas not designated for immediate evacuation because:

   a. It positions the public to receive additional instructions; and

   b. It may provide protection equal to or greater than evacuation.

6. Sheltering is usually not appropriate where high doses are projected or for exposure lasting longer than two complete air exchanges of the shelter.

7. Because sheltering may be implemented in less time than evacuation, it may be the temporary protective action of choice if rapid evacuation is impeded by a) certain environmental conditions--e.g. severe weather or floods; b) health constraints--e.g. patients and workers

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[3]Each State has the responsibility for formulating guidance to define when (and if) the public should be given potassium iodide. Planning for its use is discussed in "Potassium Iodide as a Thyroid-blocking Agent in a Radiation Emergency: Final Recommendations on Use" (FD-82).

in hospitals and nursing homes; or c) long mobilization times--e.g. certain industrial and farm workers, or prisoners and guards; d) physical constraints to evacuation--e.g. inadequate roads.

8. If a major release of radioiodine or particulate materials occurs, inhalation dose may be the controlling criterion for protective actions. In this case:

a. Breathing air filtered through common household items (e.g., folded wet handkerchiefs or towels) may be of significant help, if appropriate precautions are taken to avoid possible suffocation.

b. After confirmation that the plume has passed, shelters should be opened to avoid airborne activity trapped inside, and persons should leave high exposure areas as soon as possible after cloud passage to avoid exposure to deposited radioactive material.

c. Consideration should be given to the prophylactic administration of potassium iodide (KI) as a thyroid-blocking agent to emergency workers, workers in critical industries, or others in accordance with the PAGs in Table 2-1 and reference FD-82.

9. If dose from external gamma radiation is the controlling criterion, shelter construction and size are the most important considerations; ventilation control and filtering are less important. The main factors which reduce whole body external dose are; a) wall thickness and size of structure, b) number of stories overhead, c) central location within the structure, and d) the height of the cloud with respect to the building.

5.6 Procedures for Calculating Dose Conversion Factors

This section provides information used in the development of the DCFs in Tables 5-1 and 5-2. Three exposure pathways are included: whole body exposure to gamma radiation from the plume, inhalation from the plume, and whole body exposure to gamma radiation from deposited materials. Although exposure of the skin from beta radiation could be significant, evaluations show that other exposure pathways will be controlling for evacuation and sheltering decisions. Therefore, DCFs for skin are not provided. Individual DCFs for the three exposure pathways are provided in the following sections. They are each expressed in terms of the time-integrated air concentration so that they may be combined to yield a composite DCF for each radionuclide that reflects all three pathways. These data may be used to facilitate revising the DCFs in Tables 5-1 and 5-2 when more specific or technically improved assumptions are available, as well as to evaluate the relative importance of the individual pathways for specific radionuclide mixes.

5.6.1 External Exposure to Gamma Radiation from the Plume

Table 5-3 provides DCFs and DRLs for external exposure to gamma radiation due to immersion in contaminated air. The values for gamma radiation will provide conservative estimates for exposure to an overhead plume. They are derived under the assumption that the plume is correctly approximated by a semi-infinite source.

The DCFs given in Table 5-3 are used to calculate the effective dose equivalent from external exposure to gamma radiation from the plume. They are based on dose-rate conversion factors for effective dose in Table A.1 of reference DO-88. The units given in Table A.1 are converted to those in Table 5-3 as follows:

$$\frac{mrem \cdot y^{-1}}{\mu Ci \cdot m^{-3}} \times 0.1142 = \frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$$

Only the short-lived daughters of Ru-106 and Cs-137 emit gamma radiation and, therefore, the DCFs from Table A.1 for these entries are attributable to their daughters. The DCF for Ce-144 is combined with that for its short-lived daughter; it is assumed they are in equilibrium. Since the DRLs apply to a PAG of 1 rem, they are simply the reciprocals of the DCFs.

5.6.2 Inhalation from the Plume

Table 5-4 provides DCFs and DRLs for committed effective dose equivalent due to inhalation of an airborne plume of radioactive particulate materials and for committed dose equivalent to the thyroid due to inhalation of radioiodines. It is assumed that the radionuclides are in the chemical and physical form that yields the highest dose, and that the particle size is one micrometer mean aerodynamic diameter. For other chemical and physical forms of practical interest the doses may differ, but in general only by a small factor. If the chemical and/or physical form (e.g. solubility class or particle size) is known or can be predicted, the DCFs for inhalation should be adjusted as appropriate.

The dose factors and breathing rate used to develop the DCFs in Table 5-4 are those given in Table 2.1 of Federal Guidance Report No.11 and were derived for "standard man" (EP-88). Although the DCFs for some radionuclides would be slightly higher for children, the conservatism in the PAGs and procedures for their application provide an adequate margin for safety. The advantage of using a single source of current data for the development and timely revision of DCFs for these and any other relevant radionuclides is also a consideration in the selection of this data base for use in emergency response applications.

The units given in Table 2-1 of EP-88 are converted to the units in Table 5-4, using a breathing rate of 1.2E+6 $cm^3 \cdot h^{-1}$, by the factor

$$Sv \cdot Bq^{-1} \cdot 4.4E+12 = \text{rem per } \mu Ci \cdot cm^{-3} \cdot h.$$

The DRLs are simply the reciprocal of the DCF.

5.6.3 External Dose from Deposited Materials

Table 5-5 provides DCFs and DRLs for 4-day exposure to gamma radiation from selected radionuclides following deposition of particulate materials on the ground from a plume. The deposition velocity (assumed to be 1 cm/s for iodines and 0.1 cm/s for other particulate materials) could vary widely depending on the physical and chemical characteristics of the deposited material and the surface, and meteorological conditions. In the case of precipitation, the amount of deposition (and thus the dose conversion factors for this exposure pathway) will be much higher. To account for the ingrowth of short-lived daughters in deposited materials after measurements are made, the tabulated values include their contribution to dose over the assumed 4-day period of exposure. Because the deposition velocity can be much lower or higher than assumed in developing the dose conversion factors for deposited materials, decision makers are cautioned to pay particular attention to actual measurements of gamma exposure from deposited materials for evacuation decisions after plume passage.

The objective is to calculate DCFs for single radionuclides in terms of effective dose equivalent from 4 days exposure to gamma radiation from deposited radioactive materials. In order to be able to sum the dose conversion factors with those for other exposure pathways, the DCF is expressed in terms of dose per unit time-integrated air concentration, where the deposition from the plume is assumed to occur at approximately the beginning of the incident. The following equation was used to generate Table 5-5:

$$DCF = V_g \cdot DCRF \cdot 1.14E\text{-}3\left[\frac{1-e^{-\lambda t}}{\lambda}\right]$$

Where:

DCF = the dose per unit air concentration ($\mu Ci \cdot cm^{-3} \cdot h$)

V_g = the deposition velocity, assumed to be 3600 $cm \cdot h^{-1}$ for iodines and 360 $cm \cdot h^{-1}$ for other particulate materials

$DRCF$ = the dose rate conversion factor ($mrem \cdot y^{-1}$ per $\mu Ci \cdot m^{-2}$) (DO-88)

1.14E-3 = a factor converting $mrem \cdot y^{-1}$ per m^2 to $rem \cdot h^{-1}$ per cm^2

λ = the decay constant for the radionuclide (h^{-1})

t = duration of exposure (hours),assumed to be 96 hours (4 days)

Table 5-3 Dose Conversion Factors (DCF) and Derived Response Levels (DRL) for External Exposure Due to Immersion in Contaminated Air

Radionuclide	DCF[a] rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[b] $\mu Ci \cdot cm^{-3} \cdot h$
H-3	0.0E+00	0.0E+00
C-14	0.0E+00	0.0E+00
Na-22	1.3E+03	7.8E-04
Na-24	2.7E+03	3.7E-04
P-32	0.0E+00	0.0E+00
P-33	0.0E+00	0.0E+00
S-35	0.0E+00	0.0E+00
Cl-36	4.8E-06	2.1E+05
K-40	9.2E+01	1.1E-02
K-42	1.7E+02	6.0E-03
Ca-45	9.3E-09	1.1E+08
Sc-46	1.2E+03	8.4E-04
Ti-44	7.7E+01	1.3E-02
V-48	1.7E+03	5.8E-04
Cr-51	1.8E+01	5.6E-02
Mn-54	5.0E+02	2.0E-03
Mn-56	1.1E+03	9.4E-04
Fe-55	1.3E-02	7.6E+01
Fe-59	7.0E+02	1.4E-03
Co-58	5.8E+02	1.7E-03
Co-60	1.5E+03	6.7E-04
Ni-63	0.0E+00	0.0E+00
Cu-64	1.1E+02	9.2E-03
Zn-65	3.4E+02	2.9E-03
Ge-68	5.2E-02	1.9E+01
Se-75	2.3E+02	4.4E-03
Kr-85	1.3E+00	7.8E-01
Kr-85m	9.3E+01	1.1E-02
Kr-87	5.1E+02	2.0E-03
Kr-88	1.3E+03	7.8E-04

Table 5-3, Continued

Radionuclide	DCF[a] rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[b] $\mu Ci \cdot cm^{-3} \cdot h$
Kr-89	1.2E+03	8.6E-04
Rb-86	5.6E+01	1.8E-02
Rb-88	4.1E+02	2.5E-03
Rb-89	1.3E+03	7.7E-04
Sr-89	8.2E-02	1.2E+01
Sr-90	0.0E+00	0.0E+00
Sr-91	4.1E+02	2.4E-03
Y-90	0.0E+00	0.0E+00
Y-91	2.1E+00	4.7E-01
Zr-93	0.0E+00	0.0E+00
Zr-95	4.3E+02	2.3E-03
Zr-97	1.1E+02	9.3E-03
Nb-94	9.3E+02	1.1E-03
Nb-95	4.5E+02	2.2E-03
Mo-99	9.1E+01	1.1E-02
Tc-99	3.0E-04	3.3E+03
Tc-99m	7.6E+01	1.3E-02
Ru-103	2.8E+02	3.6E-03
Ru-105	4.6E+02	2.2E-03
Ru/Rh-106[c]	1.2E+02	8.4E-03
Pd-109	3.9E-01	2.5E+00
Ag-110m	1.6E+03	6.2E-04
Cd-109	1.3E+00	8.0E-01
Cd-113m	0.0E+00	0.0E+00
In-114m	5.2E+01	1.9E-02
Sn-113	4.8E+00	2.1E-01
Sn-123	4.1E+00	2.4E-01
Sn-125	1.8E+02	5.4E-03
Sn-126	2.8E+01	3.6E-02
Sb-124	1.1E+03	8.8E-04

Table 5-3, Continued

Radionuclide	DCF[a] rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[b] $\mu Ci \cdot cm^{-3} \cdot h$
Sb-126	1.6E+03	6.2E-04
Sb-127	3.9E+02	2.6E-03
Sb-129	8.6E+02	1.2E-03
Te-127m	1.8E+00	5.6E-01
Te-129	3.1E+01	3.2E-02
Te-129m	2.0E+01	5.1E-02
Te-131m	8.5E+02	1.2E-03
Te-132	1.2E+02	8.0E-03
Te-134	5.1E+02	2.0E-03
I-125	6.3E+00	1.6E-01
I-129	4.8E+00	2.1E-01
I-131	2.2E+02	4.6E-03
I-132	1.4E+03	7.4E-04
I-133	3.5E+02	2.9E-03
I-134	1.6E+03	6.4E-04
I-135	9.5E+02	1.1E-03
Xe-131m	4.9E+00	2.0E-01
Xe-133	2.0E+01	5.0E-02
Xe-133m	1.7E+01	5.9E-02
Xe-135	1.4E+02	7.0E-03
Xe-135m	2.5E+02	4.1E-03
Xe-137	1.1E+02	9.2E-03
Xe-138	7.1E+02	1.4E-03
Cs-134	9.1E+02	1.1E-03
Cs-136	1.3E+03	7.8E-04
Cs/Ba-137[c]	3.5E+02	2.9E-03
Cs-138	1.4E+03	6.9E-04
Ba-133	2.1E+02	4.8E-03
Ba-139	2.1E+01	4.9E-02
Ba-140	1.1E+02	9.3E-03

Table 5-3, Continued

Radionuclide	DCF[a] rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[b] $\mu Ci \cdot cm^{-3} \cdot h$
La-140	1.4E+03	7.1E-04
La-141	2.5E+01	3.9E-02
La-142	1.8E+03	5.6E-04
Ce-141	4.4E+01	2.3E-02
Ce-143	1.5E+02	6.6E-03
Ce-144	1.0E+01	9.7E-02
Ce/Pr-144[c]	3.1E+01	3.2E-02
Nd-147	7.6E+01	1.3E-02
Pm-145	9.5E+00	1.0E-01
Pm-147	2.1E-03	4.8E+02
Pm-149	6.7E+00	1.5E-01
Pm-151	1.9E+02	5.2E-03
Sm-151	5.2E-04	1.9E+03
Eu-152	6.7E+02	1.5E-03
Eu-154	7.4E+02	1.3E-03
Eu-155	3.3E+01	3.1E-02
Gd-153	5.1E+01	2.0E-02
Tb-160	6.4E+02	1.6E-03
Ho-166m	9.4E+02	1.1E-03
Tm-170	2.7E+00	3.8E-01
Yb-169	1.6E+02	6.1E-03
Hf-181	3.1E+02	3.2E-03
Ta-182	7.6E+02	1.3E-03
W-187	2.7E+02	3.6E-03
Ir-192	4.7E+02	2.1E-03
Au-198	2.3E+02	4.3E-03
Hg-203	1.3E+02	7.6E-03
Tl-204	5.8E-01	1.7E+00
Pb-210	7.6E-01	1.3E+00
Bi-207	9.1E+02	1.1E-03

Table 5-3, Continued

Radionuclide	DCF[a] rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[b] $\mu Ci \cdot cm^{-3} \cdot h$
Bi-210	0.0E+00	0.0E+00
Po-210	5.1E-03	2.0E+02
Ra-226	3.9E+00	2.6E-01
Ac-227	7.2E-02	1.4E+01
Ac-228	5.5E+02	1.8E-03
Th-227	6.0E+01	1.7E-02
Th-228	1.1E+00	8.9E-01
Th-230	2.2E-01	4.5E+00
Th-232	1.1E-01	9.4E+00
Pa-231	1.7E+01	5.8E-02
U-232	1.5E-01	6.6E+00
U-233	1.4E-01	7.3E+00
U-234	8.7E-02	1.1E+01
U-235	8.8E+01	1.1E-02
U-236	6.9E-02	1.4E+01
U-238	5.9E-02	1.7E+01
U-240	4.1E-01	2.4E+00
Np-237	1.3E+01	7.6E-02
Np-239	9.6E+01	1.0E-02
Pu-236	6.8E-02	1.5E+01
Pu-238	5.0E-02	2.0E+01
Pu-239	4.7E-02	2.1E+01
Pu-240	4.9E-02	2.0E+01
Pu-241	0.0E+00	0.0E+00
Pu-242	4.2E-02	2.4E+01
Am-241	1.1E+01	9.2E-02
Am-242m	2.7E-01	3.7E+00
Am-243	2.9E+01	3.4E-02
Cm-242	5.6E-02	1.8E+01
Cm-243	7.3E+01	1.4E-02

Table 5-3, Continued

Radionuclide	DCF[a] rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[b] $\mu Ci \cdot cm^{-3} \cdot h$
Cm-244	4.8E-02	2.1E+01
Cm-245	4.1E+01	2.5E-02
Cm-246	4.0E-02	2.5E+01
Cf-252	4.3E-02	2.3E+01

[a]DCFs are expressed in terms of committed effective dose equivalent and are based on data from reference (DO-88).

[b]Assumes a PAG of one rem committed effective dose equivalent.

[c]The contribution from the short-lived daughter is included in the factors for the parent radionuclide.

Table 5-4 Dose Conversion Factors (DCF) and Derived Response Levels (DRL) for Doses Due to Inhalation[a]

Radionuclide	Lung Class	DCF rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[b] $\mu Ci \cdot cm^{-3} \cdot h$
H-3	V[c]	7.7E+01	1.3E-02
C-14	L ORG C[d]	2.5E+03	4.0E-04
Na-22	D	9.2E+03	1.1E-04
Na-24	D	1.5E+03	6.9E-04
P-32	W	1.9E+04	5.4E-05
P-33	W	2.8E+03	3.6E-04
S-35	W	3.0E+03	3.4E-04
Cl-36	W	2.6E+04	3.8E-05
K-40	D	1.5E+04	6.7E-05
K-42	D	1.6E+03	6.1E-04
Ca-45	W	7.9E+03	1.3E-04
Sc-46	Y	3.6E+04	2.8E-05
Ti-44	Y	1.2E+06	8.2E-07
V-48	W	1.2E+04	8.2E-05
Cr-51	Y	4.0E+02	2.5E-03
Mn-54	W	8.0E+03	1.2E-04
Mn-56	D	4.5E+02	2.2E-03
Fe-55	D	3.2E+03	3.1E-04
Fe-59	D	1.8E+04	5.6E-05
Co-58	Y	1.3E+04	7.7E-05
Co-60	Y	2.6E+05	3.8E-06
Ni-63	Vapor	7.5E+03	1.3E-04
Cu-64	Y	3.3E+02	3.0E-03
Zn-65	Y	2.4E+04	4.1E-05
Ge-68	W	6.2E+04	1.6E-05
Se-75	W	1.0E+04	9.8E-05
Rb-86	D	7.9E+03	1.3E-04
Rb-88	D	1.0E+02	1.0E-02
Rb-89	D	5.2E+01	1.9E-02
Sr-89	Y	5.0E+04	2.0E-05

Table 5-4, Continued.

Radionuclide	Lung Class	DCF rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[b] $\mu Ci \cdot cm^{-3} \cdot h$
Sr-90	Y	1.6E+06	6.4E-07
Sr-91	Y	2.0E+03	5.0E-04
Y-90	Y	1.0E+04	9.9E-05
Y-91	Y	5.9E+04	1.7E-05
Zr-93	D	3.8E+05	2.6E-06
Zr-95	D	2.8E+04	3.5E-05
Zr-97	Y	5.2E+03	1.9E-04
Nb-94	Y	5.0E+05	2.0E-06
Nb-95	Y	7.0E+03	1.4E-04
Mo-99	Y	4.8E+03	2.1E-04
Tc-99	W	1.0E+04	1.0E-04
Tc-99m	D	3.9E+01	2.6E-02
Ru-103	Y	1.1E+04	9.3E-05
Ru-105	Y	5.5E+02	1.8E-03
Ru/Rh-106[c]	Y	5.7E+05	1.7E-06
Pd-109	Y	1.3E+03	7.6E-04
Ag-110m	Y	9.6E+04	1.0E-05
Cd-109	D	1.4E+05	7.3E-06
Cd-113m	D	1.8E+06	5.5E-07
In-114m	D	1.1E+05	9.4E-06
Sn-113	W	1.3E+04	7.8E-05
Sn-123	W	3.9E+04	2.6E-05
Sn-125	W	1.9E+04	5.4E-05
Sn-126	W	1.2E+05	8.4E-06
Sb-124	W	3.0E+04	3.3E-05
Sb-126	W	1.4E+04	7.1E-05
Sb-127	W	7.2E+03	1.4E-04
Sb-129	W	7.7E+02	1.3E-03
Te-127m	W	2.6E+04	3.9E-05
Te-129	D	1.1E+02	9.3E-03

Table 5-4, Continued.

Radionuclide	Lung Class	DCF rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[b] $\mu Ci \cdot cm^{-3} \cdot h$
Te-129m	W	2.9E+04	3.5E-05
Te-131m	W	7.7E+03	1.3E-04
Te-132	W	1.1E+04	8.8E-05
Te/I-132[e]	W	1.2E+04	8.5E-05
Te-134	D	1.5E+02	6.5E-03
I-125	D	2.9E+04	3.4E-05
I-129	D	2.1E+05	4.8E-06
I-131	D	3.9E+04	2.5E-05
I-132	D	4.6E+02	2.2E-03
I-133	D	7.0E+03	1.4E-04
I-134	D	1.6E+02	6.3E-03
I-135	D	1.5E+03	6.8E-04
Cs-134	D	5.6E+04	1.8E-05
Cs-136	D	8.8E+03	1.1E-04
Cs/Ba-137[e]	D	3.8E+04	2.6E-05
Cs-138	D	1.2E+02	8.2E-03
Ba-133	D	9.4E+03	1.1E-04
Ba-139	D	2.1E+02	4.9E-03
Ba-140	D	4.5E+03	2.2E-04
La-140	W	5.8E+03	1.7E-04
La-141	D	7.0E+02	1.4E-03
La-142	D	3.0E+02	3.3E-03
Ce-141	Y	1.1E+04	9.3E-05
Ce-143	Y	4.1E+03	2.5E-04
Ce-144	Y	4.5E+05	2.2E-06
Ce/Pr-144[e]	Y	4.5E+05	2.2E-06
Nd-147	Y	8.2E+03	1.2E-04
Pm-145	Y	3.7E+04	2.7E-05
Pm-147	Y	4.7E+04	2.1E-05
Pm-149	Y	3.5E+03	2.8E-04

Table 5-4, Continued.

Radionuclide	Lung Class	DCF rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[b] $\mu Ci \cdot cm^{-3} \cdot h$
Pm-151	Y	2.1E+03	4.8E-04
Sm-151	W	3.6E+04	2.8E-05
Eu-152	W	2.7E+05	3.8E-06
Eu-154	W	3.4E+05	2.9E-06
Eu-155	W	5.0E+04	2.0E-05
Gd-153	D	2.9E+04	3.5E-05
Tb-160	W	3.0E+04	3.3E-05
Ho-166m	W	9.3E+05	1.1E-06
Tm-170	W	3.2E+04	3.2E-05
Yb-169	Y	9.7E+03	1.0E-04
Hf-181	D	1.9E+04	5.4E-05
Ta-182	Y	5.4E+04	1.9E-05
W-187	D	7.4E+02	1.3E-03
Ir-192	Y	3.4E+04	3.0E-05
Au-198	Y	3.9E+03	2.5E-04
Hg-203	D	8.8E+03	1.1E-04
Tl-204	D	2.9E+03	3.5E-04
Pb-210	D	1.6E+07	6.1E-08
Bi-207	W	2.4E+04	4.2E-05
Bi-210	D	1.9E+04	5.4E-05
Po-210	D	1.1E+07	8.9E-08
Ra-226	W	1.0E+07	9.7E-08
Ac-227	D	8.0E+09	1.2E-10
Ac-228	D	3.7E+05	2.7E-06
Th-227	Y	1.9E+07	5.2E-08
Th-228	Y	4.1E+08	2.4E-09
Th-230	W	3.9E+08	2.6E-09
Th-232	W	2.0E+09	5.1E-10
Pa-231	W	1.5E+09	6.5E-10
U-232	Y	7.9E+08	1.3E-09

Table 5-4, Continued.

Radionuclide	Lung Class	DCF rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[b] $\mu Ci \cdot cm^{-3} \cdot h$
U-233	Y	1.6E+08	6.2E-09
U-234	Y	1.6E+08	6.3E-09
U-235	Y	1.5E+08	6.8E-09
U-236	Y	1.5E+08	6.6E-09
U-238	Y	1.4E+08	7.0E-09
U-240	Y	2.7E+03	3.7E-04
Np-237	W	6.5E+08	1.5E-09
Np-239	W	3.0E+03	3.3E-04
Pu-236	W	1.7E+08	5.8E-09
Pu-238	W	4.7E+08	2.1E-09
Pu-239	W	5.2E+08	1.9E-09
Pu-240	W	5.2E+08	1.9E-09
Pu-241	W	9.9E+06	1.0E-07
Pu-242	W	4.9E+08	2.0E-09
Am-241	W	5.3E+08	1.9E-09
Am-242m	W	5.1E+08	2.0E-09
Am-243	W	5.3E+08	1.9E-09
Cm-242	W	2.1E+07	4.8E-08
Cm-243	W	3.7E+08	2.7E-09
Cm-244	W	3.0E+08	3.4E-09
Cm-245	W	5.5E+08	1.8E-09
Cm-246	W	5.4E+08	1.8E-09
Cf-252	Y	1.9E+08	5.3E-09
		Thyroid Dose	
Te/I-132[e]	W/D	2.9E+05	1.8E-05
I-125	D	9.6E+05	5.2E-06
I-129	D	6.9E+06	7.2E-07
I-131	D	1.3E+06	3.9E-06

Table 5-4, Continued.

Radionuclide	Lung Class	DCF rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[b] $\mu Ci \cdot cm^{-3} \cdot h$
I-132	D	7.7E+03	6.5E-04
I-133	D	2.2E+05	2.3E-05
I-134	D	1.3E+03	3.9E-03
I-135	D	3.8E+04	1.3E-04

[a]These factors and levels apply to adults (IC-75) and are based on Federal Guidance Report No. 11 (EP-88). They are also based on the lung class that results in the most restrictive value. DCFs are expressed in terms of committed effective dose equivalent, except for those for thyroid dose, which are in terms of committed dose equivalent.

[b]DRLs are based on a dose of 1 rem committed effective dose equivalent, except those for thyroid dose radionuclides, which are based on a committed dose equivalent of 5 rem.

[c]V denotes water vapor.

[d]L ORG C denotes labelled organic compounds.

[e]Contributions from short-lived daughters are included in the factors for parent radionuclides.

Table 5-5 Dose Conversion Factors (DCF) and Derived Response Levels (DRL) for a 4-Day Exposure to Gamma Radiation from Deposited Radionuclides[a]

Radionuclide	DCF[b] rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[b,c] $\mu Ci \cdot cm^{-3} \cdot h$
H-3	0.0E+00	0.0E+00
C-14	0.0E+00	0.0E+00
Na-22	8.3E+03	1.2E-04
Na-24	3.1E+03	3.2E-04
P-32	0.0E+00	0.0E+00
P-33	0.0E+00	0.0E+00
S-35	0.0E+00	0.0E+00
Cl-36	1.8E-04	5.4E+03
K-40	5.4E+02	1.9E-03
K-42	1.8E+02	5.7E-03
Ca-45	8.4E-07	1.2E+06
Sc-46	7.5E+03	1.3E-04
Ti-44	6.7E+02	1.5E-03
V-48	1.0E+04	1.0E-04
Cr-51	1.3E+02	7.8E-03
Mn-54	3.3E+03	3.0E-04
Mn-56	2.4E+02	4.1E-03
Fe-55	8.7E-01	1.1E+00
Fe-59	4.2E+03	2.4E-04
Co-58	3.8E+03	2.6E-04
Co-60	8.9E+03	1.1E-04
Ni-63	0.0E+00	0.0E+00
Cu-64	1.5E+02	6.8E-03
Zn-65	2.1E+03	4.7E-04
Ge-68	4.5E+00	2.2E-01
Se-75	1.7E+03	5.9E-04
Rb-86	3.3E+02	3.0E-03
Rb-88	1.0E+01	9.8E-02
Rb-89	2.9E+01	3.4E-02
Sr-89	5.2E-01	1.9E+00

Table 5-5, Continued.

Radionuclide	DCF[b] rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[b,c] $\mu Ci \cdot cm^{-3} \cdot h$
Sr-90	0.0E+00	0.0E+00
Sr-91	3.8E+02	2.6E-03
Y-90	0.0E+00	0.0E+00
Y-91	1.3E+01	7.8E-02
Zr-93	0.0E+00	0.0E+00
Zr-95	2.9E+03	3.5E-04
Zr-97	1.7E+02	5.8E-03
Nb-94	6.3E+03	1.6E-04
Nb-95	2.9E+03	3.4E-04
Mo-99	4.0E+02	2.5E-03
Tc-99	2.5E-03	4.0E+02
Tc-99m	5.3E+01	1.9E-02
Ru-103	1.9E+03	5.2E-04
Ru-105	2.1E+02	4.7E-03
Ru/Rh-106[d]	8.3E+02	1.2E-03
Pd-109	5.6E-01	1.8E+00
Ag-110m	1.2E+02	8.2E-03
Cd-109	3.7E+01	2.7E-02
Cd-113m	0.0E+00	0.0E+00
In-114m	3.8E+02	2.7E-03
Sn-113	5.9E+01	1.7E-02
Sn-123	2.6E+01	3.9E-02
Sn-125	1.0E+03	1.0E-03
Sn-126	2.4E+02	4.1E-03
Sb-124	6.8E+03	1.5E-04
Sb-126	9.9E+03	1.0E-04
Sb-127	1.9E+03	5.2E-04
Sb-129	3.7E+02	2.7E-03
Te-127m	2.6E+01	3.8E-02
Te-129	3.9E+00	2.6E-01

Table 5-5, Continued.

Radionuclide	DCF[b] rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[b,c] $\mu Ci \cdot cm^{-3} \cdot h$
Te-129m	1.4E+02	7.2E-03
Te-131m	3.5E+01	2.8E-02
Te-132	6.6E+02	1.5E-03
Te/I-132[d]	6.7E+03	1.5E-04
Te-134	3.8E+01	2.7E-02
I-125	9.5E+02	1.0E-03
I-129	8.7E+02	1.2E-03
I-131	1.3E+04	7.4E-05
I-132	3.1E+03	3.2E-04
I-133	7.3E+03	1.4E-04
I-134	1.3E+03	7.5E-04
I-135	5.7E+03	1.8E-04
Cs-134	6.2E+03	1.6E-04
Cs-136	7.6E+03	1.3E-04
Cs/Ba-137[d]	2.4E+03	4.1E-04
Cs-138	6.8E+01	1.5E-02
Ba-133	1.7E+03	6.1E-04
Ba-139	3.2E+00	3.1E-01
Ba-140	7.0E+02	1.4E-03
La-140	4.1E+03	2.4E-04
La-141	8.9E+00	1.1E-01
La-142	2.3E+02	4.3E-03
Ce-141	3.3E+02	3.0E-03
Ce-143	4.8E+02	2.1E-03
Ce-144	8.5E+01	1.2E-02
Ce/Pr-144[d]	2.0E+02	5.0E-03
Nd-147	5.2E+02	1.9E-03
Pm-145	1.1E+02	8.7E-03
Pm-147	1.6E-02	6.2E+01
Pm-149	2.8E+01	3.6E-02

Table 5-5, Continued.

Radionuclide	DCF[b] rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[b,c] $\mu Ci \cdot cm^{-3} \cdot h$
Pm-151	5.5E+02	1.8E-03
Sm-151	2.1E-02	4.9E+01
Eu-152	1.5E+01	6.7E-02
Eu-154	4.8E+03	2.1E-04
Eu-155	2.8E+02	3.5E-03
Gd-153	5.0E+02	2.0E-03
Tb-160	4.1E+03	2.4E-04
Ho-166m	6.5E+03	1.5E-04
Tm-170	2.4E+01	4.1E-02
Yb-169	1.3E+03	7.4E-04
Hf-181	2.2E+03	4.5E-04
Ta-182	4.8E+03	2.1E-04
W-187	6.6E+02	1.5E-03
Ir-192	3.4E+03	3.0E-04
Au-198	1.1E+03	9.5E-04
Hg-203	9.6E+02	1.0E-03
Tl-204	5.1E+00	2.0E-01
Pb-210	1.2E+01	8.5E-02
Bi-207	6.0E+03	1.7E-04
Bi-210	0.0E+00	0.0E+00
Po-210	3.4E-02	3.0E+01
Ra-226	3.0E+01	3.3E-02
Ac-227	8.4E-01	1.2E+00
Ac-228	3.3E+02	3.0E-03
Th-227	4.3E+02	2.3E-03
Th-228	1.1E+01	9.2E-02
Th-230	3.6E+00	2.8E-01
Th-232	2.6E+00	3.8E-01
Pa-231	1.4E+02	7.1E-03
U-232	4.1E+00	2.5E-01

Table 5-5, Continued.

Radionuclide	DCF[b] rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[b,c] $\mu Ci \cdot cm^{-3} \cdot h$
U-233	2.0E+00	5.1E-01
U-234	3.2E+00	3.1E-01
U-235	6.7E+02	1.5E-03
U-236	2.9E+00	3.5E-01
U-238	2.5E+00	3.9E-01
U-240	3.3E+00	3.0E-01
Np-237	1.3E+02	7.8E-03
Np-239	4.5E+02	2.2E-03
Pu-236	3.9E+00	2.6E-01
Pu-238	3.4E+00	3.0E-01
Pu-239	1.5E+00	6.7E-01
Pu-240	3.2E+00	3.1E-01
Pu-241	0.0E+00	0.0E+00
Pu-242	2.7E+00	3.7E-01
Am-241	1.2E+02	8.5E-03
Am-242m	1.1E+01	9.2E-02
Am-243	2.6E+02	3.8E-03
Cm-242	3.7E+00	2.7E-01
Cm-243	5.8E+02	1.7E-03
Cm-244	3.3E+00	3.1E-01
Cm-245	3.4E+02	3.0E-03
Cm-246	2.9E+00	3.5E-01
Cf-252	2.5E+00	4.0E-01

[a]Entries are calculated for gamma exposure at 1 meter above the ground surface (DO-88).

[b]All radioactivity is assumed to be deposited at the beginning of the incident. Deposition velocities are taken as 1 $cm \cdot sec^{-1}$ for radioiodines and 0.1 $cm \cdot sec^{-1}$ for other radionuclides. (See p. 5-24).

[c]Assumes a PAG of 1 rem committed effective dose equivalent.

[d]Contributions from short-lived daughters are included in the factors for parent radionuclides.

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